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Swine Research
Progress Report No. 2

Roman L. Hruska U.S. Meat Animal Research Center
in Cooperation With
University of Nebraska, Agricultural Research Division,
The Institute of Agriculture and Natural Resources

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CONTENTS

NUTRITION

ROMAN L. HRUSKA
U.S. MEAT ANIMAL RESEARCH CENTER[1]

1. Overview of Center: The U.S. Meat Animal Research Center (MARC) was authorized by Congress on June 16, 1964, thereby creating a single facility that provides an unusual opportunity for making major contributions to the solution of problems facing the U.S. livestock industry. Development of the 35,000-acre facility started in the spring of 1966 and is continuing at the present time. Phase I construction, consisting of an office-laboratory building for intensive investigations, was completed in January 1971. These facilities provide a physical plant for 42 scientists and about 200 support personnel. Phase II construction, consisting of the Meats Research Laboratory and Agricultural Engineering Building, was completed in October 1977 and provides a physical plant for 25 scientists and about 60 support personnel. Phase III construction will provide facilities for a comprehensive research program of producing, harvesting, handling, storing, and using forages in livestock production systems. Approximately 35 additional scientists and 65 support personnel will be required for this phase. Currently, one-third of the scientific staffing is completed.

Approximately 50 percent of the research program is devoted to beef cattle, 30 percent to swine, and 20 percent to sheep. Current research program objectives require breeding-age female populations of approximately 7,000 cattle (17 breeds), 4,000 sheep (8 breeds), and 600 swine litters (8 breeds) per year.

The research program at the Center is organized on a multidisciplinary basis and is directed toward providing new technology for the U.S. livestock industry by extending investigations into new areas not now being adequately studied. The research program complements research conducted elsewhere by the U.S. Department of Agriculture and is cooperative with the University of Nebraska Agricultural Research Division and other land grant university agricultural experiment stations throughout the country.

On October 10, 1978, the President signed into law a bill renaming the U.S. Meat Animal Research Center the Roman L. Hruska U.S. Meat Animal Research Center. The purpose of the bill was to honor former Nebraska Senator Roman L. Hruska for "his efforts in the establishment of a centralized facility for the research, development, and study of meat animal production in the United States."

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[1]Agricultural Research Service-U.S. Department of Agriculture, the University of Nebraska, and other cooperating land grant universities.

2. Overview on the Swine Research Program: MARC's swine research program places the highest priority on developing technology capable of having an immediate and major impact on the swine industry. Although the program is largely oriented toward fundamental research, emphasis is placed on the generation of technology that can be practically implemented by small farmers and commercial swine producers alike within a relatively short time frame.

Currently, we have 10 scientist "equivalents" conducting research in the swine program at MARC. They are working in 8 primary thrust areas and have 27 experiments under way. In addition, they are coworkers on three major projects away from MARC. Also, MARC has an active postdoctoral and visiting scientist program, which supports the swine research program.

This report represents a cross section of our swine research program at the present time. Since some of the projects from which results are reported are still in progress, the preliminary nature of some of the results must be recognized. However, it is our opinion that information useful to the industry should be provided at the earliest possible time. Progress reports of this nature will be released periodically to make current results available to the industry. For the reader's convenience, the table of contents of this report is organized by the disciplinary unit which is taking the lead in each specific problem area. The articles within the body of the report are arranged as they most closely relate in subject matter.

3. Appreciation: I want to express my appreciation to Margie McAlhany, MARC Information Officer, and Ted Acton, Swine Operations Manager, for serving as co-editors of this report. I also want to thank Linda Kelly for proofreading the report. These individuals have contributed many hours to the completion of this report.

Robert R. Oltjen, Director
Roman L. Hruska
U.S. Meat Animal Research Center

Swine Facilities and Management

Ted W. Acton, Jenell A. Dague, Ed McReynolds, Wayne T. Peshek, Cheryl R. Vap, and Patrick J. Reiman[1]

The Swine Operations Unit provides support (animals, facilities, management, and labor) for the seven research units at MARC. Researchers conduct approximately 40 projects each year in the swine area. These projects require over 4,000 pigs produced from 600 litters in five farrowing seasons each year. The swine area is staffed with nine full-time employees.

Long-term breeding and genetics projects initially populated the swine area with eight breeds (Yorkshire, Landrace, Chester White, Large White, Duroc, Hampshire, Spot, and Pietrain). There are currently two composites (4-way crosses) of these eight breeds maintained in the population (a white composite and a colored composite). Durocs are the only purebreds remaining, as they are required for ongoing research. In addition, there are two specially selected lines of lean and obese crossbred pigs. These lines were originally developed at the Beltsville Agricultural Research Center (BARC) in Maryland.

The herd was established from lab pigs and has been a closed herd for eight years. Each person entering the area is required to shower and change clothing as a disease-prevention measure. The area is enclosed and all animals maintained in confinement buildings.

Facilities

The facilities in the swine area (see Fig. 1) are all total confinement. All buildings use a flush system for manure handling. Most of the barns use a negative air pressure ventilation system. The barns that use natural ventilation have screened air inlets to prevent bird access. Nipple waters are used in all buildings except the farrowing barn.

The breeding and gestation barns (61, 62, and 72) have a one-time capacity of approximately 900 head under the current management scheme. This includes 195 individual stalls and 70 pens for 10 or 20 head. The stalls are used for bred females (prior to their entering the farrowing house) and for boars. These barns are also used for the collection of puberty data on more than 600 gilts per year.

The farrowing barn (60) has 96 farrowing crates in four rooms with 24 crates per room. These crates are a conventional 5 ft x 7 ft and are installed on a concrete floor. Two ft at the back of each crate is either woven wire flooring or concrete slats. There is hot water heating in the floor under the creep areas of the pen. Electric heat lamps are used the first few days after farrowing and then removed.

The nursery barn (67) is divided into four rooms with 22 pens per room. It has capacity for approximately 880 pigs. Two of the rooms have raised decks of expanded metal. The other two rooms have a concrete floor with woven wire flooring in the front and back of each pen.

The finishing barns (64, 65, 66, 69, 70, and 73) have a one-time capacity of approximately 1,500 head. Two of the barns (69 and 70) are traditional modified open-front barns that utilize doors rather than curtains. The remainder are totally environmentally controlled. Pen size varies from 1 to 20 head per pen, depending on experimental requirements.

Feeders and feed can be weighed in all barns to obtain feed efficiency data. Scales are available in three of the finishing barns, as many of the projects require a mininum of monthly weights to be taken on the animals. Four other animal scales are also utilized in the swine area.

A special-use barn (68) is designed for projects that require special pen arrangements or utilize small numbers of animals. It has a one-time capacity of approximately 110 head. The surgery building (63) has a penned area for pre- and post-surgery recovery, a prep room, and a surgery room. There are approximately 300 surgeries performed annually. The remaining building (74) is the shower facility.

Standard Management Practices

Breeding is done by single-sire mating. When females are detected in estrus, they are bred twice, approximately 12 and 24 h after the onset of estrus. Information collected at breeding (animal numbers, date, breed, pen location, and standing score) is recorded and stored in a database computer system. Numerous lines are maintained within each population to minimize inbreeding.

Gilts entering the breeding herd are vaccinated for erysipelas, leptospirosis, psuedorabies, and parvovirus prior to the breeding season. Seventy-five percent of the farrowings are gilts, and no female remains in the herd for more than three farrowings. All females are fed 3 1/2 lb standard gestation ration (Table 5) through breeding and the first part of gestation. The last month of gestation they are fed 4 lb of the same ration. Females are housed in group pens (10 to 20 head per pen) during breeding and most of gestation. They are maintained in gestation crates for at least two weeks prior to entering the farrowing house.

The farrowing house is basically managed as an all-in/all-out facility, with cleaning, disinfecting, fumigating, and sealing of the concrete floor performed between farrowings. Females enter the farrowing house at 110 days of gestation. They are weighed and fed the standard laction ration (Table 6). The feeding rate is reduced at farrowing and then is adjusted to each individual's requirements, which are dependent upon litter size and condition. At weaning, sows are weighed and returned to the gestation barns to be rebred or sold.

Piglets are processed within 24 h of birth. Processing involves notching ears, docking tails, clipping needle teeth, and injecting iron dextran. Data that are collected at farrowing include birth weight, nipple count, sex, vigor, sow temperature, and nervous score. At 14 days, a second injection of iron dextran is given, and males not retained for breeding are castrated. The standard creep ration (Table 1) is offered at this time.

Weaning occurs at 28 days of age. Pigs are weighed and transferred by litter to the nursery (10 to 12 pigs per pen). They are started on the standard creep ration for a few days and then gradually introduced to the standard nursery ration (Table 2) to minimize stress. All pigs are weighed at 8 weeks of age, pen assignments are made, and most pigs are moved to finishing pens by 10 weeks of age. The nursery is managed in an all-in/all-out system with cleaning and disinfecting conducted between each group. The temperature is maintained at 76 to 80° F throughout the nursery phase.

[1]Acton is the swine operations manager; Dague is an agricultural research technician, growing-finishing area; McReynolds is an agricultural research technician, breeding and gestation area; Peshek is an agricultural research technician, farrowing and nursery area; Vap is a clerical assistant, Swine Operations Unit; and Reiman is an agricultural research technician, Feedmill, MARC.

During the growing-finishing phase, pigs are fed *ad lib* the standard grower ration (Table 3) until approximately 140 lb and then the standard finishing ration (Table 4) until market weight (an average of 220 lb). Finishing barns are managed as an an all-in/all-out system as much as possible. Pens are cleaned and disinfected and the floors sealed between groups.

Standard Rations

All swine diets are ground and mixed in a horizontal, paddle-type mixer at the MARC feedmill. Vitamin and trace mineral supplements are described in Tables 7 and 8.
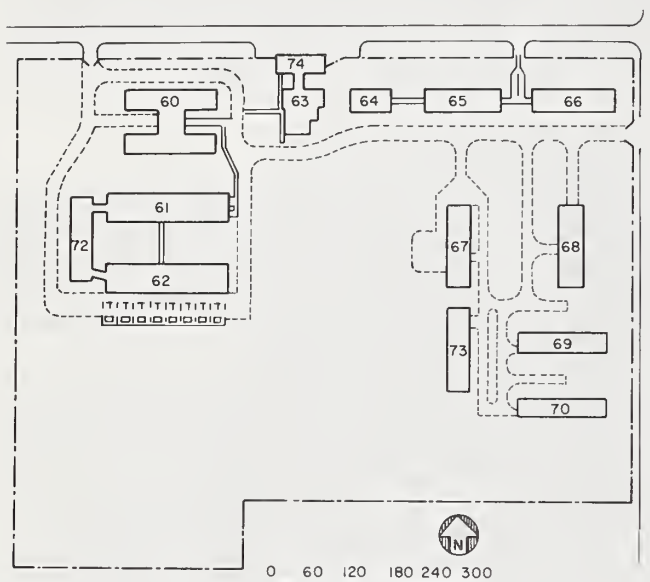
Figure 1 — Key To Buildings

60. Farrowing	67. Nursery
61. Breeding and Gestation	68. Special-Use Barn
62. Breeding and Gestation	69. Finishing
63. Surgery	70. Finishing
64. Finishing	72. Breeding and Gestation
65. Finishing	73. Finishing
66. Finishing	74. Shower Building

Table 1.—Creep diet

Ingredient	Pct
Corn	40.2
Soybean meal	30.0
Steamed rolled oats	10.0
Dicalcium phosphate	3.5
Limestone	0.3
Whey	5.0
Dextrose	5.0
Fat	5.0
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 2.—Starter diet

Ingredient	Pct
Corn	55.8
Soybean meal	25.0
Dicalcium phosphate	2.4
Limestone	0.8
Oats	10.0
Whey	5.0
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 3.—Grower diet

Ingredient	Pct
Corn	76.5
Soybean meal	19.6
Dicalcium phosphate	2.4
Limestone	0.5
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 4.—Finishing diet

Ingredient	Pct
Corn	82.1
Soybean meal	14.0
Dicalcium phosphate	2.4
Limestone	0.5
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 5.—Gestation diet

Ingredient	Pct
Corn	84.1
Soybean meal	11.0
Dehydrated alfalfa	1.0
Dicalcium phosphate	2.4
Limestone	0.5
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 6.—Lactation diet

Ingredient	Pct
Corn	76.0
Soybean meal	19.1
Dehydrated alfalfa	1.0
Dicalcium phosphate	2.4
Limestone	0.5
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline Chloride	0.2

Table 7.—Vitamin premix #9

Ingredient	Pct
Vitamin A	1,200,000 IU/lb
Vitamin D	160,000 IU/lb
Vitamin E	8,000 IU/lb
Vitamin K	800 mg/lb
Riboflavin	1,200 mg/lb
d-Pantothenic Acid	4,800 mg/lb
Niacin	6,400 mg/lb
Vitamin B_{12}	6 mg/lb
Thiamine	500 mg/lb
Biotin	50 mg/lb
Folic Acid	200 mg/lb

Table 8.—Trace mineral G

Ingredient	Pct
Calcium	<16.000
Calcium	>14.000
Copper	0.500
Iron	8.000
Manganese	1.000
Zinc	5.000
Selenium	0.005

Anaerobic Digestion of Swine Manure

Yud-Ren Chen and Andrew G. Hashimoto[1]

Introduction

The potential annual production of methane from swine manure produced in the U.S. is about 53 billion cu ft, which is equivalent to 8.3 million barrels of oil annually. This is based on the assumption that about 40 percent of the swine manure produced in the U.S. is economically collectable.

The technical feasibility of anaerobic digestion of swine manure has been demonstrated by many researchers. To better assimilate the research results and, further, to recommend the optimum designs of the anaerobic digestion systems of swine manure requires kinetic analysis of the research data. Kinetic analysis involves studying how factors, such as influent concentration, solids retention time, digestion temperature, etc., affect the methane production rate. Kinetics of the anaerobic digestion of swine manure and their design implications have been studied at MARC.

Kinetics of Methane Production

We have derived kinetic equations for methane production from organic wastes. From the kinetic equations, we found that the methane yield (volume of methane produced per mass of volatile solids added to the digester, B) is directly related to the ultimate methane yield (B_0) and inversely proportional to the solids hydraulic retention time (HRT) used. The digestion temperature will affect the maximum growth rate of bacteria responsible for methane production, which, in turn, affects the methane yield. Also, there is a kinetic parameter (K), which affects the methane yield. We found that the daily methane production per volume of digester not only varies with B_0, K, and the maximum specific growth rate of the microorganism, it is also directly proportional to the organic loading rate (L), i.e., daily amount of organic waste loaded per volume of the digester.

Ultimate methane yield, B_0. It has been shown that the maximum methane yield of an organic waste, B_0, does not depend on digestion temperature. For livestock wastes, however, it has been shown that B_0 depends on the animal species, ration, age of the manure, collection and storage method, and amount of foreign material (such as dirt and bedding) incorporated into the waste. Manure from animals fed high-grain rations generally had a greater B_0 value than manure from animals fed rations higher in roughage.

Table 1 shows the ultimate methane yield of swine manure. The ultimate methane yield of swine manure ranged from 5.1 to 8.3 cu ft methane per lb volatile solids (VS). Table 1 also shows that the manure from swine fed a barley-based ration has a lower B_0 value than that from swine fed a corn-based ration.

Maximum specific growth rate. The maximum specific growth rate of the microorganism depends on the digestion temperature. In general, the maximum specific growth rate of the microorganism increases as temperature increases up to 140°F, and at 149°F it drops sharply. We have summarized the results and further proposed that it is a linear function of the digestion temperature for temperatures ranging from 86°F to 140°F. Table 2 tabulates the maximum specific growth rate at different digestion temperatures. At 95°F, the maximum specific growth is 0.33 per day. This shows that the minimum hydraulic retention time is three days at 95°F. This is consistent with the value reported earlier by other researchers.

Kinetic parameter, K. Kinetic equations show that B and the volumetric methane production rate both decrease as K increases. K is an indicator of the overall performance of the digester (e.g., K is low for an efficient digester). K may depend on the mass transfer or inhibitory substances in the wastes. In animal manure digestion, high concentrations of volatile fatty acids and ammonia inhibit digester performance, which is reflected in the value of K.

Figure 1 is a graph of K *vs* the influent VS concentration of swine manure with digestion temperatures ranging from 95° to 131°F. Figure 1 also shows that K remains relatively constant at a value of 0.6 for low influent VS concentrations (S_{T_0}). However, for influent VS concentrations above 5.5 percent, K increases sharply. This indicates some kind of inhibition of the digester at high influent VS concentrations.

Design Implications

Influent volatile solids concentration and hydraulic retention time. Figure 2 demonstrates that the methane yield decreases when the influent VS concentration increases above 4 percent. At long retention times, the decrease in methane yield at high VS concentrations is not as pronounced as at short retention times.

Using Figure 2, methane yield can be obtained at a given influent concentration, retention time, and ultimate methane yield. For swine manure (at a low influent VS concentration) to reach 90 percent of the potential methane yield at 95°F requires a retention time of about 20 days.

Figure 3 shows volumetric methane production rate as a function of hydraulic retention time for swine waste at 95°F. At a constant influent VS concentration, as the hydraulic retention time is decreased, volumetric methane production rate increases until the system is loaded to its limit and yields the maximum volumetric methane production rate. Further decreases in the hydraulic retention time result in a sharp decrease of the volumetric methane production rate. There is, therefore, a hydraulic retention time where the volumetric methane production rate is a maximum.

Figure 3 also shows that, for a given hydraulic retention time, higher methane production rates are possible at higher influent VS concentrations. However, this holds true only when the influent VS concentration is at or below 5 percent for swine manure. Figure 3 shows that, for a hydraulic retention time less than 8.4 days, the methane production rate is lower for an influent VS concentration of 6 percent than for 5 percent. At a hydraulic retention time longer than 8.4 days, the 6 percent concentration has a higher yield than that of the 5 percent concentration.

Loading rate. Figure 4 shows that at a constant influent VS concentration, the methane yield of the swine manure decreases when the loading rate is increased. For a constant loading rate, the higher the influent VS concentration, the higher the methane yield. However, when the influent

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[1]Chen is an agricultural engineer and Hashimoto is the research leader, Agricultural Engineering Unit, MARC.

Table 1.—Ultimate methane yield of swine manure

Data from	Ultimate methane yield B_0 (cubic ft/lb VS added)	Remarks
Ianotti *et al.*, 1979	7.1	Corn-based - High energy
Kroeker *et al.*, 1979	8.3	Corn-based - High energy
Stevens and Schulte, 1979	7.7	Corn-based - High energy
Fischer *et al.*, 1975	7.2	Corn-based - High energy
Hashimoto, 1984	7.7	Corn-based - High energy
Van Velsen, 1981	5.1	Average value
Summers and Bousfield, 1980	5.8	Barley-based ration

Table 2.—Maximum specific growth rate varies with digestion temperature

Digestion temperature	86	95	104	113	122	131	140
Maximum specific growth rate (day^{-1})	0.261	0.326	0.391	0.456	0.521	0.586	0.651

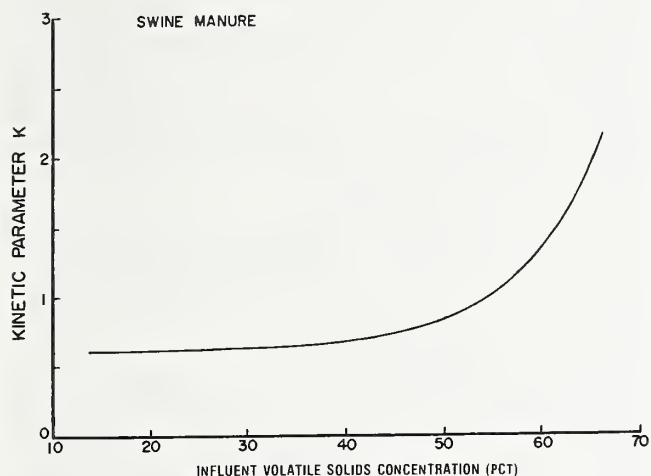Figure 1—A graph of K *vs* influent volatile solids concentration for digestion of swine manure.
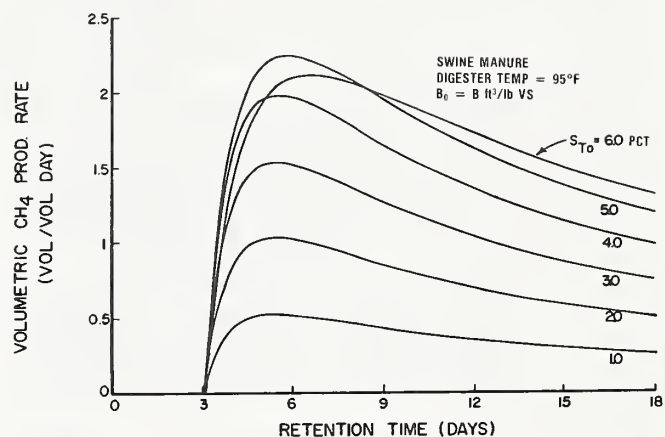

Figure 3—Graph of volumetric methane production rate from swine manure *vs* hydraulic retention time at 95°F.
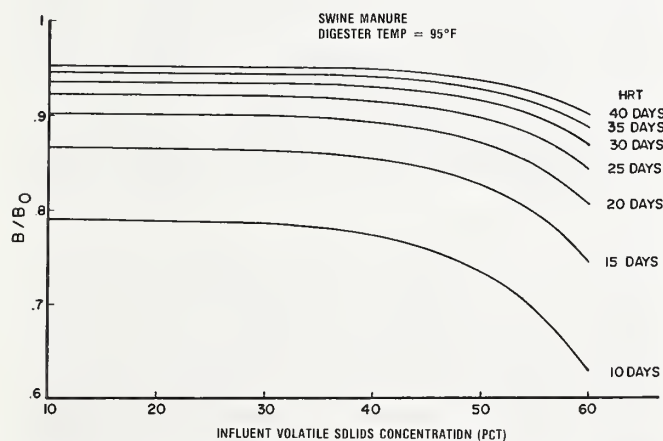

Figure 2—Methane yield from digestion of swine manure varies with the influent volatile solids concentration and hydraulic retention time.
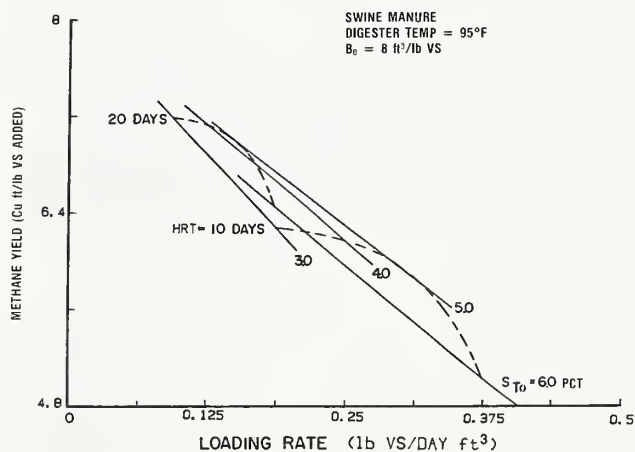

Figure 4—Graph of methane yield from swine manure at 95°F *vs* loading rate.

VS concentration increases beyond 5 percent (optimum concentration), the methane yield decreases. The dashed lines in Figure 4 are constant retention time lines, which show that as the loading rate increases, the methane yield is relatively constant until the influent VS concentration is increased beyond 5 percent, when there is a sharp drop in the methane yield.

Net thermal energy production. Since most anaerobic digesters are operated at temperatures above ambient temperature, the thermal energy needed to maintain the digester temperature is one of the most important energy inputs to anaerobic digestion systems. Net thermal energy production is defined as the methane energy production minus the heat energy requirements. A computer program describing the anaerobic digestion system has been completed based on the following constraints. The digester working volume to actual tank volume ratio is assumed to be 0.8; and digesters with a total working volume less than 28,000 cu ft are assumed to have a working tank height-to-diameter ratio of 1:0, thus limiting tank height to 33 ft. Tanks larger than 28,000 cu ft are designed with a maximum tank height of 33 ft and sufficient diameter to accommodate the volume. The maximum tank diameter is assumed to be 259 ft, resulting in a maximum tank volume of 177,000 cu ft. Systems requiring greater volume are designed with multiple tanks.

The following discussion is based on the output of the computer program assuming an ambient temperature of 50°F, and the top, sides, and bottom of each digester is insulated with materials having an overall heat transfer coefficent of 0.1 Btu/h ft²F. Boiler efficiency is assumed to be 70 percent. The VS content of swine manure is assumed to be 80 percent of the total solids.

Effect of hydraulic retention time on net thermal energy production. Figure 5 shows the net thermal energy production of a swine manure digester as a function of hydraulic retention time, assuming daily swine manure processing of 2,200 lb of dry solids and B_0 equals 8 cu ft methane per lb VS.

Figure 5 shows that, with a constant influent VS concentration, the net thermal energy production increases as hydraulic retention time increases. However, the rate of increase decreases at longer hydraulic retention times. So there is an optimum hydraulic retention time, after which further increases do not significantly increase the net thermal energy production.

Figure 5 also demonstrates that, as the influent VS concentration increases from 2 to 5 percent, there is an increase (up to 55 pct) in the net thermal energy production. A further increase of the influent VS concentration results in a decrease in the net thermal energy production. This indicates that the optimum influent VS concentration for net thermal energy production from swine manure is below 6 percent. At very low influent VS concentrations or low hydraulic retention times, the digester would not produce enough methane to offset the heat energy requirements, resulting in negative net thermal energy production.

Effect of loading rate on net thermal energy production. Figure 6 is a graph of net thermal energy production as a function of the VS loading rate. It shows that the net thermal energy production decreases sharply as the loading rate increases. For a plant size of 2,200 lb total solids (TS)/day, the net thermal energy production decreases from 10.1 million Btu per day to 5.6 million Btu per day as the loading rate increases from 0.125 to 0.5 lb VS per cu ft digester volume at 5.5 percent influent VS concentration. This represents a reduction of hydraulic retention time from 27.5 to 6.9 days. Figure 6 also shows that the optimal influent VS concentration for net thermal energy produc-

tion is 5.5 percent, which is slightly higher than the optimum influent VS concentration for methane yield (5 pct, Fig. 4).

Comparing Mesophilic and Thermophilic Digestion Systems. Although a biogas digester operating in the thermophilic temperature range (113-140°F) will have a higher reaction rate than one operating in the mesophilic temperature range (68-113°F), it will also have a higher thermal energy requirement. The question to be answered is whether the higher energy production, due to the higher reaction rate at the higher digestion temperature, will offset the additional heat energy requirement to maintain the digester at that higher temperature.

Figure 7 compares the net thermal energy production of systems at 95° and 131°F for swine manure. The following input parameters are used: ultimate methane yield is 8 cu ft per lb VS; influent VS concentration is 5 percent; ambient temperature is 50°F; and plant size is 2,200 lb TS per day. Figure 7 shows that the net thermal energy production of a system operated at 131°F will be higher than that of a system operated at 95°F if the hydraulic retention time is shorter than 8.6 days. However, if the retention time is longer than 8.6 days, the net thermal energy production of the system at 95°F will be much higher than that of the system at 131°F. If 50 percent of the effluent heat is recovered and used for heating the influent, the retention time increases from 8.6 to 13.5 days when the systems at 95° and 131°F produce the same amount of net thermal energy.

It can be concluded that a higher digestion temperature will only result in greater net thermal energy production at short retention times. Without effluent heat recovery, a system at 95°F will produce more net thermal energy than a system at 131°F for the retention times conventionally used (longer than 10 days).

Maximizing methane production per unit cost. Since the capital and operational costs of an anaerobic digestion system are generally proportional to the 0.7 power of the digester volumes, a Relative Cost Index (CI) of the digestion system was defined. CI gives the relative cost of the digestion system as compared to a digestion system of 35,000 cu ft.

The net thermal energy production per unit Relative Cost Index (NEPC) of the digester was defined as the net thermal energy production per unit CI and was used to compare the economics of the digestion system.

Figure 8 gives the NEPC of digestion systems for swine manure operating at 95° and 131°F as functions of retention time. Figure 8 shows that optimal retention times occur at 8.2 and 5.0 days where NEPC is maximized for 95° and 131°F. If 50 percent of the effluent heat is recovered and used for heating the influent, the optimal retention time decreases to 7.5 days for systems at 95°F and to 4.5 days at 131°F.

However, comparing the NEPC for 95° and 131°F in Figure 8 shows that the system at 131°F does not have an economic advantage (i.e., higher NEPC) over 95°F, if both systems are operated at a retention time longer than 8 days. It also shows that the system at 131°F has little economic advantage over 95°F if both are operated at the optimal retention times (5.0 days for 131°F and 8.2 days for 95°F). However, if there is a 50 percent effluent heat recovery, the system at 131°F will have a much higher NEPC than the system at 95°F.

Although the response of the model shows that the optimal retention times for energy production cost occur below 9 days, it should be noted that the data for digesters successfully operated below 9 days were either from laboratory-scale or pilot-scale digester studies. More

studies on pilot-scale digestion systems using swine manure with retention times shorter than 10 days are needed. For a practical design, a safety factor for reliable operation of the digestion system has to be considered along with economic factors and may dictate design considerations.

Figure 5—Net thermal energy production of a digester utilizing swine manure as a function of hydraulic retention time.

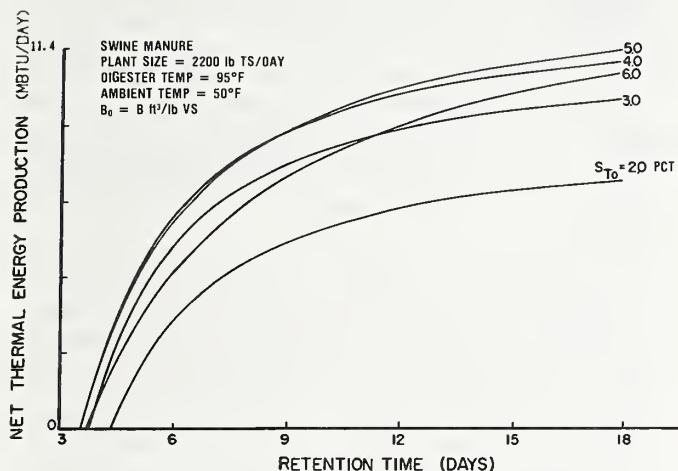

Figure 6—Net thermal energy production of a mesophilic digester utilizing swine manure as a function of loading rate.
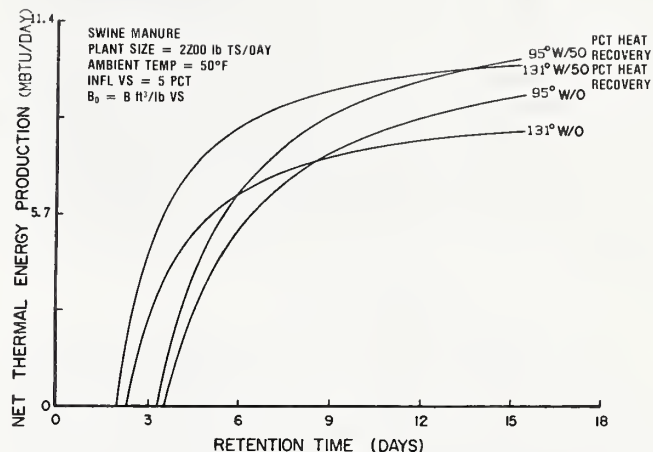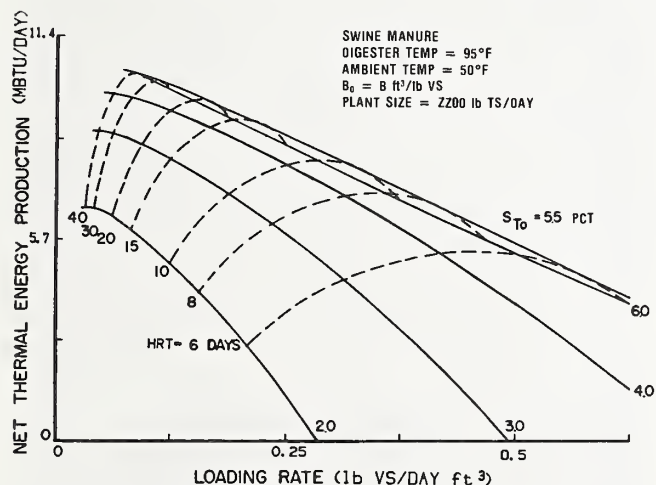

Figure 7—Comparison of the net thermal energy production from swine manure digested at 95° and 131°F.
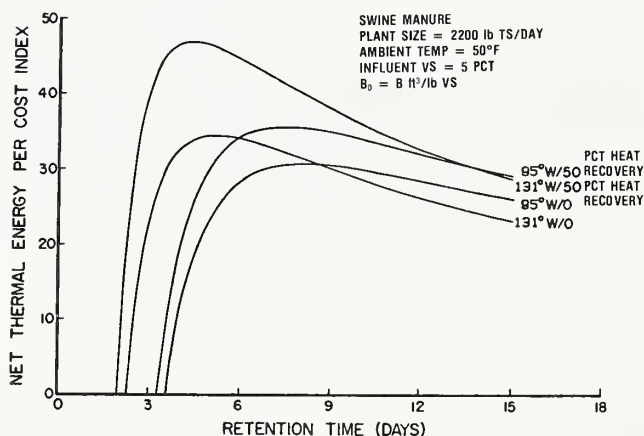

Figure 8—Comparison of net thermal energy production per Relative Cost Index for swine manure digestion systems operating at 95° and 131°F.

Adaptation of Gilts and Sows to Tether and Gestation Stalls

Barbara A. Becker, G. LeRoy Hahn, and John A. Nienaber[1]

Introduction

Animal care to limit stress and improve production efficiency is a primary concern to livestock producers. A variety of people, from producers to researchers to animal welfarists, have an interest in the question: What are the levels of stress that occur in farm animals during activities associated with life in current or future production facilities and systems? In 1981, several researchers at eight universities and two ARS locations joined an ARS-funded effort to develop some objective answers to this question. MARC scientists focused on the hormonal and behavioral responses of gilts and sows placed in conventional gestation stalls and tether stalls. This report examines the concept of stress and appropriate measures and presents a synopsis of the results and conclusions from the MARC study.

The concept of stress

Stress remains an elusive target for explicit definition. It can be identified by a disruption of a biological parameter which itself is affected by both exogenous and endogenous factors. There is no simple, single indication or measure of stress, even though severe stress is usually associated with reduced performance and economic loss. Readily observable, immediate responses such as changes in behavior, panting, and heart rate, although indicative of problem situations, are not necessarily valid indicators of stress, and may well be totally unrepresentative of long-term chronic effects. One commonly-accepted indicator of animal stress is altered physiological status. The well-being of an animal is an integration of physiological, behavioral, immunological, and possibly psychological components. Recent theoretical models recognize that all of these are influenced by the animal's perception of threats to its well-being. Presently we must rely on combinations of behavioral, hormonal, and immunological observations to determine appropriate bases for improved animal care. Although fundamental aspects are crucial for evaluating the effects of acute and chronic stress, an important role remains for animal performance, health, and longevity when assessing the integrated effects of facilities and production systems.

Historically, measurements and evaluation of stress have been based on Selye's concept of stress as first proposed in the 1930's. Selye's theoretical concept of the response induced by stress is summarized by his General Adaptation Syndrome (GAS). This syndrome consists of three phases: 1) the alarm stage, considered an immediate reaction in which adaptation has not been acquired; 2) the resistance stage, when adaptation is optimum; 3) the exhaustion phase, in which acquired adaptation is lost, and death or other adverse consequences result. Selye's work was based on the hypothesis that, no matter what the identity of stressors, the physiological changes were relatively the same and were characterized by adrenal gland response.

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There are, however, other hypotheses relevant to evaluation of stress. The psychobiological concept of stress, hypothesized by Mason in 1971, recognized psychological and emotional components of stress as a vital part of stress-induced responses. In 1960, the "arousal" theory was developed by Berlyne, in which variables such as novelty, uncertainty, and conflict were recognized. He emphasized that these variables required a certain amount of perception, assimilation, and evaluation of events by the animal, based upon previous experiences and comparisons. Animal responses to such arousal incorporated not only physiological changes, but also behavioral changes.

Regardless of the concept, stress, as normally discussed in biological terms, results from exposure to a stressor. A stressor can be classified as acute, chronic, repeated, or "crossed" with another. Ultimately, it may or may not affect an animal's well-being. Factors such as genetics, health, age, experience, and reproductive status can influence a particular animal's response. The disruption of a biological parameter may or may not be carried over to performance- or health-related measures. Correlative associations between behavior, for example, and physiology or performance have not demonstrated strong relationships.

Adaptive capabilities of animals must be considered in evaluating stress responses of livestock and their ultimate welfare. Stress, while most often considered only in a negative connotation as it may lead to impaired function, can also be a positive influence when it leads to coping and adaptation. Living organisms are tremendously resilient, and there is, *within limits*, an impetus to grow, develop, and reproduce despite adverse conditions. Behavioral and physiological coping actions are normal adaptive responses of animals to potential stressors which permit normal functions to continue. Only when threshold limits, which are also influenced by many factors, are exceeded does impaired function become a reality which may result in reduced performance or health. These limits are illustrated in Figure 1, which shows a recent model incorporating coping capabilities of the animal and potential consequences of exceeding threshold limits.

Studies conducted in the past several years have demonstrated that there are husbandry conditions that: 1) can be detrimental to the well-being, health, or performance of farm animals; 2) may initially impose a stress on the animals but to which the animals adapt in a short period of time; 3) may be perceived by humans as stressful to the animals but are not perceived as such by the animals. Difficulties in interpreting the various research results are related to the high level of individual variation in measures of stress. The variations result in part from differences in coping strategies and capabilities among animals, in part from the ambiguity and confusion that relates to the concept of "stress," and in part from the uncertainty that specific measurements are adequate to evaluate stress.

Swine stress studies at MARC

The studies reported here presume that the adrenal system response, as represented by blood serum cortisol level, is a valid indicator of the presence or absence of
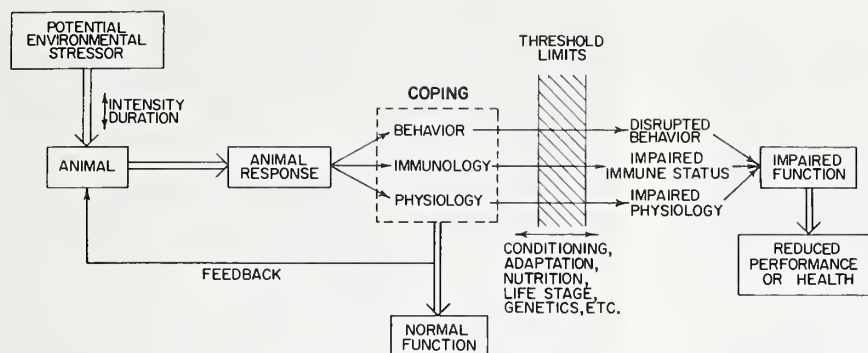
Figure 1—Responses of animals to potential environmental stressors which can influence performance and health.
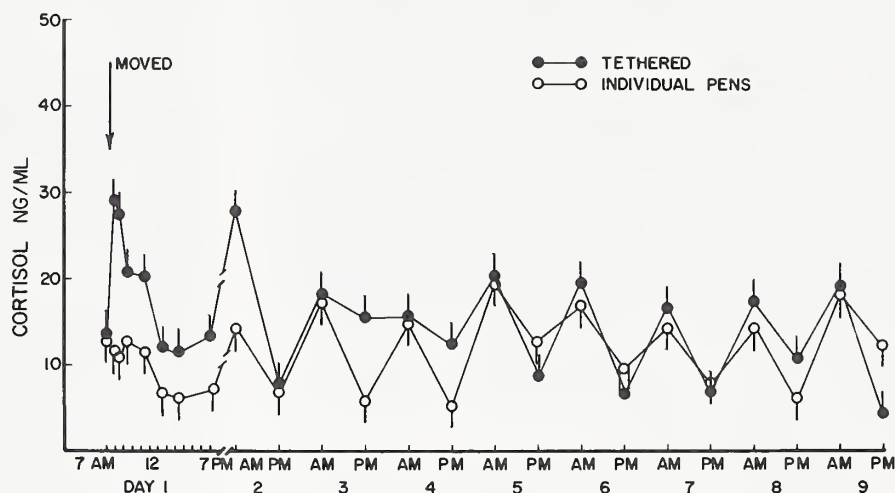
Figure 2—Serum cortisol concentration (mean ± SE) in gilts moved into tether stalls or individual pens on day 1 and at daily a.m. and p.m. collection times for 9 days thereafter.

stress in the animal subject. The validity of serum cortisol as an indicator has been established in studies at MARC and elsewhere, but there is still controversy about the degree of accuracy. The cortisol measures, supplemented by concurrent behavioral observations, form the basis of our conclusions.

Five experiments were conducted at MARC from 1981 to 1984 to evaluate endocrine and behavioral responses of prepartum gilts and sows to individual penning arrangements within intensive swine housing systems. Objectives of the experiments were to examine: 1) the endocrine and behavioral patterns of gilts and sows in response to penning arrangements; 2) the time required for acclimation; 3) the effects of previous penning and handling; 4) whether or not penning during gestation affected subsequent response in the farrowing crate and associated farrowing performance; and 5) the presence of any chronic changes in endocrine and behavioral responses if acclimation occurs. The experimental procedures and the information obtained are summarized and discussed.

Procedure

Penning arrangements used were individual pens (for control animals), gestation stalls, and tether stalls, all within totally-enclosed housing. Individual pens used for control animals were 8 ft x 6 ft. Gestation stalls were 1.6 ft wide by 6 ft long with metal side panels. Tether stalls were 2 ft wide, with metal side panels 3 ft long; the girth tethers were anchored to the floor with a 1 ft chain, unless otherwise noted.

Crossbred gilts and sows (Yorkshire x Landrace, or similar) were used for all experiments in the study. Indwelling jugular catheters were used to minimize disturbance of the animals during blood sample collections. Blood samples were analyzed for cortisol concentrations by radioimmunoassay. Animal activities were recorded by a time-lapse videorecorder. Activities were classified as standing, lying, sitting, eating-posture, head movements, and bar-biting (only possible for gilts in tether stalls), and the percentage of time spent at each activity was calculated.

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Results

Experiment 1. Unbred gilts not previously handled by swine personnel were used for this experiment. Measures of serum cortisol concentrations were determined by gilts moved to tethers after previous tethering for two weeks (Group I), moved to tethers from individual pens (Group II), or moved to individual pens from individual pens (Group III). No significant differences were obtained among the three treatments over the total 60-h sampling period. However, cortisol levels in Group II were elevated at .5, 1, and 2 h after placement in tethers when compared to levels of Groups I and III.

Experiment 2. Unbred gilts in this experiment had routinely been handled by swine personnel. Serum cortisol concentrations were measured in gilts before and after moving from individual pens into tethers or other individual pens (Fig. 2). By .5 h after moving, cortisol for gilts in tether stalls had increased 152 percent above those moved to individual pens, and remained elevated by 90 percent at 11.5 h. Circadian rhythms of cortisol were disrupted for tethered gilts during the first 4 days after moving. On day 5, the daily rhythm of cortisol returned in the tethered gilts, with both tethered and individually penned animals demonstrating higher concentrations of cortisol in the a.m. than in the p.m. Activity measures indicated that gilts in tether stalls spent less time standing and in eating posture and more time lying than did gilts in individual pens. Percent of time spent sitting or performing head movements was similar between treatments. The percent of standing, lying, and sitting at a given time of day was similar among all gilts. A diurnal pattern of behavior was noted, with activities such as standing and sitting occurring more frequently during the morning hours. Standing activity from 10:00 a.m. to 11:30 a.m. was associated with daily feeding. Bar-biting by gilts in tether stalls generally decreased over the first 3 days of penning.

Experiment 3. Gestating second-parity sows (considered to be experienced) were moved from group pens to tether stalls, gestation stalls or individual pens. Serum cortisol concentrations were similar in all three penning arrangements during the 15-day period. After the sows were transferred to farrowing crates on the 16th day, cortisol concentrations were not different among sows from the three types of prior penning. Activity measures indicated that sows in the gestation stalls spent the least time lying down. Measures of subsequent farrowing performance indicated that sows in tethers for the 15 days prior to transfer to farrowing crates farrowed fewer live piglets than those sows in individual pens. However, there was no significant difference between the number of live piglets in tethers and gestation stalls. Number of live pigs was also not different between sows from gestation stalls and individual pens. Sows in tether stalls farrowed more stillborns than those in gestation stalls or individual pens; however, differences were not statistically significant. No differences were found in any of the other farrowing parameters.

Experiment 4. Cortisol concentrations for gilts (naive animals) were measured in a study similar to experiment 3 for the experienced sows. On days 1 and 3 of placement in the three penning arrangements, the tethered gilts had significantly higher cortisol values than either the gestation stalls or individual pens, and the gilts in gestation stalls also had higher cortisol levels than those in individual pens. By day 8, differences were no longer noted among the penning treatments. Also, prior penning had no effect on subsequent farrowing performance.

Experiment 5. In order to determine if tethering imposes a chronic stress, unbred gilts were placed in one of four treatment pens for 4 weeks: individual pens (9 ft x 6 ft), where animals had unrestricted movement; tether stalls (2 ft wide), where the gilts were restricted by a 1 ft chain and side panels (3 ft high x 2.6 ft long) such that animals were unable to turn around and had only limited movement; modified tether stalls with additional side panels (6 ft x 2 ft x 3 ft), where the animals were attached to a 6 ft chain which allowed them to move forward and backward the same distance as those in individual pens but not to turn around; and individual pens (8 ft x 8 ft) with a 1 ft tether chain such that gilts could freely turn around but with limited movement. The circadian profile of serum cortisol and the cortisol response to an ACTH challenge were greatest for the gilts in the last treatment (individual pens with 1 ft tether). Responses among all the other treatments did not differ. Behavioral testing for ambulatory ability, health and temperament examinations, and measures of immune function (neutrophil:lymphocyte ratios) were similar for all gilts regardless of penning type.

Discussion

The five experiments conducted to determine the presence or lack of adaptability of gilts and sows to various types of penning produced several significant results. First, our data demonstrated that placing mature female swine in tether stalls may or may not be stressful, with responses dependent on previous penning and handling experiences. In the first experiment, no statistical significance was found in cortisol concentrations in unbred gilts that were placed in tether stalls for the first time or for a second time after having been previously tethered for 2 weeks. Higher cortisol concentrations were observed in the first few hours for gilts tethered for the first time. However, there was much variation among animals.

In contrast, another experiment using unbred gilts that previously had been handled by humans (exp. 2) showed serum cortisol values were significantly elevated within .5 h after placement of the animals in tether stalls, with the increased cortisol levels remaining until the second day (Fig. 2). The unbred gilts in experiment 1 experienced limited human interaction, such that the variation in response may be confounded with the novelty of interacting with humans. The animals in experiment 2 had been handled extensively, and the stress of being placed in tether stalls was not confounded with handling. Previous experience (defined here as either penning and human interaction or handling of the animals) appears to affect the changes in cortisol concentrations associated with placement of gilts in tether stalls.

A second important finding from these studies was the disruption and subsequent return to the normal rhythmic pattern of the circadian cycle of cortisol as an indicator of adaptation to tether stalls (Fig. 2). Our results indicate that placement of unbred gilts in tether stalls initially disrupts the circadian rhythm, but reassociation occurred by at least day 4. Using this rhythm as an indicator, our studies also showed that placement of bred gilts in tether stalls was a novel experience, with adaptation occurring within 3 to 8 days. Bred sows, with more handling and penning experience, did not exhibit a disruption of the cortisol rhythm.

A third significant result was obtained from evaluating the behavioral responses of gilts and sows to the various penning systems. When initially penned in tether stalls, gilts spent a greater percentage of time lying and less standing, but the time at which these activities occurred was not altered. The increased lying time initially observ-

ed in gilts in tether stalls is in agreement with previous reports for tethered sows. However, in contrast to previous reports, lying activity was similar after several weeks, regardless of type of penning. These behavior data support the observed cortisol values measured in these unbred gilts which showed that the circadian rhythm of cortisol was disrupted for the first 4 days, after which the rhythm returned and was similar to the rhythm in gilts in individual pens. Our data suggest that the gilts adapt to tether stalls and that such adaptation does not require modification of time spent standing, lying, and sitting.

Eating-posture activity is a behavior that preliminary analysis of videotapes indicated might be a good indicator of stress and adaptation in gilts. On day 1, eating-posture activity occurred most frequently in the hours immediately after placement in the various pens, although this activity did not vary with type of penning. By day 2 and on day 3, no differences were found between days or penning types. This further indicates that little disruption of behavioral activities or patterns occurred after placement in gestation or tether stalls.

A fourth significant result substantiated the adaptability of crossbred swine, as our last study showed that long-term penning in tether stalls was not a chronic stress. Adaptability to such penning was indicated by the failure to find impairment of adrenal function, locomotor ability or alterations of basic behavior. The data further suggested that the limited movement imposed by tether stalls was not stressful. However, a stress may have been created when the animal perceived that its movement was severely limited in the absence of physical barriers.

Lastly, our data suggest that farrowing performance may be affected by previous housing. However, treatment effects are not definitive, and a larger number of animals would be needed to test this effect.

Conclusions

Several inferences may be drawn from the five experiments conducted to address the underlying question: Are intensive housing systems stressful to gilts and sows? While there is still much to be done to fully answer the question, these add to the growing body of objective research knowledge:

1. Data suggest that placement of prepartum sows or gilts in tether stalls and gestation stalls may or may not result in increases in serum cortisol concentrations, with this result being influenced by each animal's previous penning and handling experience.

2. Placement of inexperienced gilts in tether stalls can disrupt the circadian rhythm of serum cortisol for 3 to 8 days, after which time it reassociates. For the sow, penning in tether and gestation stalls does not disrupt the circadian rhythm of serum cortisol.

3. Tethering prior to transfer to the farrowing crate does not affect the reproductive performance response of gilts, but may affect the performance of sows.

4. Differences in percentage of time spent performing various behaviors may occur in different penning systems, but the time at which the behaviors occur is unaltered. Gross or abnormal changes in behavior are unlikely to result from the penning systems tested.

5. Tethering is not indicated to result in chronic stress, suggesting that crossbred swine are quite capable of adapting to different penning systems.

Mean Performance of Eight Swine Breeds and Two Four-Breed Composite Populations

Larry D. Young, Gordon E. Dickerson, and Kreg A. Leymaster[1]

Introduction

Efficiency of swine production can be improved significantly by applying well established genetic principles. The basic genetic tools available to the swine industry are selection programs to improve existing breeds and crossbreeding systems to utilize genetic differences among breeds and heterosis (hybrid vigor). Two long term breeding projects are being conducted at MARC to evaluate development of composite lines as a specific method of utilizing differences among breeds and heterosis. Composite lines are self-propagating populations developed from a crossbred foundation. After the initial crossing, all replacement animals come from within the population. Theoretically, a composite line developed from a crossbred population with equal contribution from four breeds should retain 75 percent of the initial heterozygosity and, hopefully, 75 percent of the initial heterosis. The objective of this report is to summarize reproduction, growth, carcass, and puberty data obtained on eight pure breeds. In addition, data will be presented on the amount of heterosis retained in advanced generations of two four-breed composites. The data on heterosis retention should be considered preliminary since the project requires two more years for completion.

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Procedure

Chester White, Swedish Landrace, Large White, and Yorkshire gilts farrowed during February of each year (spring season). Duroc, Hampshire, Pietrain, and Spot gilts farrowed annually during September and October (fall season).

Purebred litters of each breed were produced each year. In 1980 the following two-way crosses were made contemporary to the contributing purebreds: Chester White boars x Large White females and Yorkshire boars x Landrace females in spring season; reciprocal crosses of Duroc x Pietrain and Hampshire x Spot in the fall season. In 1981 four-breed cross litters (F_1) were farrowed contemporary to the contributing purebreds by making all possible four-breed cross matings within a season. In 1982, F_2 litters were produced by matings among F_1 males and females. Similarly, F_3 and F_4 litters were farrowed in 1983 and 1984. Hereafter, F_3 and F_4 litters will be considered identical genetically and referred to as F_3.

Pigs were raised by their own dams and had access to creep feed at 14 days of age. Pigs were weaned at 28 days of age into a nursery, weighed at 56 days of age, and moved to growing-finishing facilities 1 week later. Two boars and up to two barrows per litter were penned together, while gilts were penned in groups of 20 per pen. Growth and feed consumption data were recorded at 28-day intervals from 70 to 154 days of age. Carcass data were obtained on barrows at slaughter weight. Gilts were moved to another building at 154 days of age and checked daily for estrus through the first breeding season to about 9 months of age.

Table 1.—Breed means and comparisons among means for preweaning traits in the spring season

Litter breed	No. litters	Total no. born[a]	Litter traits No. born alive	No. weaned	Litter birth weight, lb[b]	Litter weaning wt, lb	Pig traits Average pig birth wt, lb	Average pig weaning wt, lb
Yorkshire (Y)	125	8.48	7.73	6.65	20.41	88.8	2.407	13.25
Landrace (L)	129	9.34	8.77	7.53	28.64	103.0	3.062	13.58
Large White (W)	127	8.24	7.72	6.42	20.77	87.7	2.518	13.56
Chester White (C)	102	8.29	7.57	5.26	21.43	70.5	2.590	13.36
Two-way crosses (TW)[c]	41	8.72	8.16	6.95	25.77	101.9	2.945	14.53
F_1[d]	42	9.22	8.80	8.16	26.63	120.8	2.906	14.75
F_2[d]	32	9.45	9.06	7.40	26.46	107.8	2.798	14.51
F_3[d]	108	9.71	9.17	8.18	27.80	118.8	2.868	14.53
Comparison								
TW-P		.13	.21	.48	2.95[f]	14.3[f]	.300[f]	1.10[f]
F_1-P		.64	.85	1.70[f]	3.81[f]	33.3[f]	.262[f]	1.32[f]
F_2-P		.86	1.11[f]	.93	3.66[f]	20.3[f]	.154[f]	1.06[f]
F_3-P		1.12[f]	1.22[f]	1.72[f]	4.98[f]	31.3[f]	.225[f]	1.10[f]
F_3-¾ F_1-¼ P[e]		.64	.58	.44	2.12	6.4	.026	.11

[a]Total of pigs born alive and stillborn.
[b]Includes weights of stillborn pigs as well as those born alive.
[c]Produced by mating C boars to W females and Y boars to L females.
[d]F_1 = C·W x Y·L, etc., F_2 = F_1 x F_1, F_3 = F_2 x F_2 and F_3 x F_3.
[e]This contrast estimates recombination effects (see text).
[f]Significantly different from zero at P < .05.

Results

Data were analyzed for pigs born in 1979 through 1984. Data from spring and fall were analyzed separately. Thus, comparisons between breeds in different seasons may include season effects as well as real breed differences. The mean performance of the eight purebreds and the various crossbred generations involved during the development of the composite line are shown in Tables 1 through 4 for several preweaning and postweaning traits. Also shown are the comparisons of each crossbred generation with the average performance of the purebreds. This comparison is an estimate of the net individual, maternal, and paternal heterosis retained in the crossbred generation. The F_3 and greater generations of the composite lines are expected to have 75 percent as many heterozygous loci as the F_1. If heterosis is retained in proportion to heterozygosity, the F_3 is expected to retain 75 percent of the heterosis present in the F_1. If the comparison "F_3 - $3/4F_1$ - $1/4\overline{P}$" is equal to zero, then 75 percent of the initial heterosis was maintained in the F_3; positive values indicate more than 75 percent was retained, while negative values indicate less than 75 percent was retained. For brevity in the discussion, this contrast will be referred to as "recombination effects," which is the genetic mechanism that would cause heterosis not to be retained in proportion to heterozygosity.

Evaluation of the differences among breed group means can be accomplished by the reader by examining Tables 1, 2, 3, and 4. However, some discussion of the recombination effects in the F_3 will be presented.

Recombination effects were not significant for any sow productivity trait in either season (Tables 1 and 2). However, estimates for litter size at birth and weaning were positive in the spring but negative in the fall. In fact, the estimates for litter size at birth were quite large and negative in the fall. The negative estimates in the fall season may be due to the unexpected high levels of heterosis in the F_1 of this cross rather than a low level in the F_3. Note that the F_3 in the spring and fall have a similar advantage over their respective purebred means.

Recombination effects were not significant for average pig weight at birth or weaning in the spring, but were significantly positive in the fall (Tables 1 and 2). The positive estimates in the fall may reflect the smaller litter size of the F_3 relative to the F_1 in that season.

Recombination effects were not large or significant for average daily gain in either season (Tables 3 and 4). In both seasons, recombination effects were positive and of similar magnitude for backfat probe but significant only in the fall. In this case, positive recombination effects were undesirable because the pigs were fatter than expected.

In the spring season, recombination effects were significant and undesirable for carcass loin eye area but not for carcass length or backfat (Table 3). Recombination effects were not significant for any carcass traits in the fall (Table 4).

Estimates of recombination effects on percent cycling and age at puberty were not significant in the spring. In the fall, recombination effects were significant and desirable for percent cycling but not for age at puberty.

In summary, it appears that recombination effects depend upon the trait and the breeds contributing to the composite. With the possible exceptions of litter size and backfat probe in the fall season and loin eye area in the spring season, it appears that the estimates of recombination effects are zero, or positive. Positive values mean more heterosis was retained than expected, which is a bonus. If these results are substantiated with the data from the next 2 years, then the development of composite lines would be a viable method of utilizing differences among breeds and heterosis. However, evaluation of the data to be collected in 1985 and 1986 will be required before a final recommendation can be made.

Table 2.—Breed means and comparisons among means for preweaning traits in the fall season

Litter breed	No. litters	Total no. born[a]	Litter traits No. born alive	No. weaned	Litter birth weight, lb[b]	Litter weaning wt, lb	Pig traits Average pig birth wt, lb	Average pig weaning wt, lb
Hampshire (H)	139	7.90	7.38	5.70	21.05	75.4	2.659	13.18
Duroc (D)	139	8.90	8.03	6.28	24.43	78.7	2.749	12.50
Pietrain (P)	135	7.32	6.70	5.34	19.80	67.5	2.703	12.61
Spot (S)	147	7.90	7.07	4.70	23.21	64.6	2.943	13.76
Two-way crosses (TW)[c]	40	7.25	6.69	4.77	21.87	68.1	3.025	14.29
F_1[d]	31	10.19	9.62	7.95	30.00	105.4	2.914	13.18
F_2[d]	36	10.60	10.04	7.99	30.49	107.1	2.881	13.23
F_3[d]	119	8.91	8.15	6.89	27.54	100.5	3.093	14.66
Contrast								
TW-P		-.76	-.61	-.74	-.26	-3.5	.260[f]	1.28[f]
F_1-P		2.19[f]	2.32[f]	2.44[f]	7.87[f]	33.7[f]	.150[f]	.20
F_2-P		2.59[f]	2.74[f]	2.49[f]	8.38[f]	35.5[f]	.117[f]	.22
F_3-P		.91[f]	.85[f]	1.39[f]	5.40[f]	28.9[f]	.331[f]	1.65[f]
F_3-3/4 F_1-1/4 P[e]		-.73	-.89	-.44	-.48	3.5	.218[f]	1.50[f]

[a]Total of pigs born alive and stillborn.

[b]Includes weights of stillborn pigs as well as those born alive.

[c]Produced by reciprocal matings of D and P and reciprocal matings of S and H.

[d]F_1 = D·P x H·S, etc., F_2 = F_1 x F_1, F_3 = F_2 x F_2 and F_3 x F_3.

[e]This estimates recombination effects (see text).

[f]Significantly different from zero at P<.05.

Table 3.—Breed means and comparisons among means for postweaning traits in the spring season

Litter breed	No. observations[a]	Daily gain by day[bc]	10th rib backfat, in[bd]	Carcass traits[e] Length, in	10th rib backfat, in	Loin eye area, in^2	Puberty traits Percent cycling[f]	Age at puberty[g]
Yorkshire (Y)	645/120/336	1.565	.619	30.83	1.118	5.192	77.4	222.6
Landrace (L)	696/145/348	1.634	.592	32.30	.996	4.603	90.4	185.0
Large White (W)	630/113/335	1.684	.572	31.80	.976	4.867	92.1	208.2
Chester White (C)	417/51/225	1.519	.641	30.59	1.075	4.944	79.4	215.8
Two-way crosses (TW)[h]	217/40/104	1.744	.599	31.33	1.063	5.162	88.0	193.2
F_1[i]	191/32/105	1.739	.621	31.78	.984	5.270	90.4	202.2
F_2[i]	175/33/100	1.711	.599	31.27	1.035	4.882	94.7	202.7
F_3[i]	518/119/269	1.702	.632	31.61	1.071	4.619	84.3	204.3
Comparison								
TW-P		.143[k]	-.007	-.07	.020	.232	3.2	-14.7[k]
F_1-P		.139[k]	.015	.43	-.067	.356[k]	5.6	-5.7
F_2-P		.110[k]	-.007	-.14	.000	-.031	9.9[k]	-5.2
F_3-P		.104[k]	.026[k]	.22	.028	-.279[k]	-.5	-3.6
F_3-¾ F_1-¼ P[j]		-.002	.015	-.10	.079	-.558[k]	-4.7	.7

[a] Number for growth and backfat/number for carcass traits/number for puberty traits.
[b] Average of boar, barrow, and gilt data.
[c] Average daily gain from 70 to 154 days of age.
[d] Adjusted to 180 lb liveweight.
[e] Adjusted to 165 lb carcass weight.
[f] Percentage of gilts with at least one estrus.
[g] Based on gilts exhibiting estrus.
[h,i,j] See footnotes c, d, e in Table 1.
[k] Significantly different from zero to P < .05.

Table 4.—Breed means and comparisons among means for postweaning traits in the fall season

Litter breed	No. observations[a]	Daily gain kg, day[bc]	10th rib backfat, in[bd]	Carcass traits[e] Length, in	10th rib backfat, in	Loin eye area, in^2	Puberty traits Percent cycling[f]	Age at puberty[g]
Hampshire (H)	617/106/256	1.549	.499	30.81	1.047	5.425	80.4	205.9
Duroc (D)	687/113/285	1.568	.609	30.61	1.134	4.743	81.4	229.8
Pietrain (P)	590/72/288	1.413	.551	28.72	1.299	5.689	89.1	199.0
Spot (S)	585/94/256	1.680	.498	31.11	1.043	5.115	93.4	195.8
Two-way crosses (TW)[h]	153/16/84	1.728	.552	30.83	1.067	5.549	88.7	185.1
F_1[i]	182/39/99	1.748	.519	30.61	1.161	5.316	92.2	193.1
F_2[i]	192/32/102	1.724	.532	29.58	1.201	5.084	95.0	195.1
F_3[i]	570/111/313	1.691	.543	30.63	1.102	5.224	101.1	193.2
Comparison								
TW-P		.176[k]	.012	.52	-.063	.294	2.7	-22.5[k]
F_1-P		.196[k]	-.020[k]	.29	.028	.062	6.1	-14.6[k]
F_2-P		.172[k]	-.008	-.74[k]	.071	-.170	8.9[k]	-12.6[k]
F_3-P		.139[k]	.004	.32	-.028	-.016	15.1[k]	-14.5[k]
F_3-¾ F_1-¼ P[j]		-.009	.019[k]	.10	-.051	-.062	10.6[k]	-3.5

[a] Number for growth and backfat/number for carcass traits/number for puberty traits.
[b] Average of boar, barrow, and gilt data.
[c] Average daily gain from 70 to 154 days of age.
[d] Adjusted to 180 lb liveweight.
[e] Adjusted to 165 lb carcass weight.
[f] Percentage of gilts with at least one estrus; data on gilts born in 1984 were unavailable.
[g] Based on gilts exhibiting estrus; data on gilts born in 1984 were unavailable.
[h,i,j] See footnotes c, d, e in Table 2.
[k] Significantly different from zero to P < .05.

Genetic Regulation of Testicular Growth and its Relationship to Female Reproduction

Larry D. Young, Kreg A. Leymaster, and Donald D. Lunstra[1]

Introduction

Testicular size has been investigated as a potential measure of degree of sexual maturity in boars. The relationship of testicular size to sperm-producing capacity in young boars has been examined by castration in other studies. Results indicated that sperm production was more advanced in boars with heavier testes. For obvious reasons, castration is not a viable method of evaluating testicular size in potential breeding boars. In situ measurements of testicular length and width have been shown to be good indicators of testicular weight and can be used to estimate testicular volume. Development of a testicular biopsy technique would also allow direct evaluation of development of sperm production without castration.

The objectives of this experiment were to (1) evaluate testicular size and function at a constant age and constant weight in eight breeds of swine, (2) estimate heritability of testicular size and function, (3) estimate genetic and phenotypic relationships among testicular traits, (4) estimate the phenotypic and genetic relationship of testicular traits with growth and backfat, and (5) estimate the genetic relationship of testicular traits with age at puberty and litter size at birth in gilts.

Procedure

In situ length and width of both testes and body weight were recorded at approximately 98, 126, and 154 days of age on 40 Chester White, 60 Landrace, 60 Large White, and 62 Yorkshire boars born in the spring, and on 57 Duroc, 54 Hampshire, 57 Pietrain, and 50 Spot boars born in the fall. Testicular biopsies from approximately one-half of the boars in each breed group were evaluated for percentage of tubules with complete spermatogenesis. The pig's own performance was used to adjust his testicular length and width to 154 days of age and to 180 lb body weight, separately. Testicular volume at 154 days of age and 180 lb body weight were estimated from the adjusted length and width. Daily gain was estimated over the interval from 98 to 154 days of age. At 154 days of age, backfat was measured with an ultrasonic device approximately 1 in off the midline at the first rib, last rib, and last lumbar vertebra. The average of the three measurements was adjusted to a body weight of 180 lb. Daughters of a sample of these boars were evaluated for age at first estrus (puberty) and number of pigs born in their first litter.

Least-squares breed means were estimated from analyses that included the effects of farrowing season, year, breed within season, sire, dam, and appropriate interactions. Phenotypic correlations were also estimated from this analysis. Heritabilities and genetic correlations were derived from the regression of the offspring's performance on the sire's performance.

Results

Breed means for testicular traits are presented in Table 1. Comparisons among breeds are valid only within a farrowing season because of the potential effect of farrowing season on testicular growth.

In the spring farrowing, Landrace, Large White, and Yorkshire had significantly larger testes than Chester White at 154 days of age. At the same age, percent spermatogenesis was significantly higher for Landrace and Large White than for Chester White or Yorkshire. Thus, the increased testicular size of Yorkshire was not associated with increased percent spermatogenesis. Higher values for percent spermatogenesis indicate that the boars are closer to sexual maturity and probably initiated sperm production at an earlier age. At a constant weight of 180 lb, Yorkshire had larger testes than the other three breeds.

In the fall season, Duroc and Hampshire had smaller testes than Pietrain and Spot at 154 days of age, although the difference between Duroc and Pietrain was not significant. In this season, the relative differences among breeds for percent spermatogenesis do not agree well with the relative differences among breeds for testicular volume at 154 days of age. Percent spermatogenesis was highest for Pietrain and lowest for Hampshire; Duroc and Spot were intermediate and equal. At a constant weight of 180 lb, Pietrain had the largest testes. The slow growth rate of the Pietrain would also make it older than the other breeds when it reached 180 lb.

Heritability estimates of testicular traits are also shown in Table 1. The heritability estimate was significant and large for testicular volume at 154 days of age but low and nonsignificant for testicular volume at 180 lb. The heritability estimate for percent spermatogenesis was moderate and not significant. Thus, selection for increased testicular size at 154 days of age would be more effective than selection for testicular size at 180 lb body weight or percent spermatogenesis.

Phenotypic correlations among testicular traits were positive and moderate in size and significant (Table 2). However, because of their magnitude, a producer should not place too much confidence in testicular size as an indicator of the development of sperm production in boars at these early ages.

The genetic correlations among testicular traits were large and positive (Table 2). This indicates that selection for increased testicular size would result in genetic improvement in sperm production at 154 days of age in boars of the next generation.

The phenotypic correlations of daily gain with testicular traits (Table 3) suggest that variation in growth is not related to variation in sperm production at 154 days of age and only lowly related to variation in testicular size at 154 days of age or 180 lb body weight. There was essentially no phenotypic relationship of backfat with any testicular traits (Table 3).

None of the genetic correlations of testicular traits with growth rate or backfat were statistically significant. However, the sign of the genetic correlations indicate that selection for increased daily gain may result in genetic improvement in testicular size at 154 days of age and, to a lesser extent, at 180 lb body weight but a decrease in sperm production at 154 days of age (Table 3). The genetic correlations also indicate that selection for decreased backfat may result in decreases in testicular size, particularly at 180 lb body weight, and in sperm production at 154 days of age.

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The genetic correlations of testicular traits with age at puberty and litter size were small and nonsignificant. Thus, selection for improved testicular traits in males is not expected to result in genetic change in age at puberty or litter size of daughters.

The results indicate that breeds vary in testicular size at 154 days of age and at 180 lb body weight and in percent spermatogenesis at 154 days of age. However, breed differences in testicular size do not necessarily correspond with breed differences in percent spermatogenesis. Boars with larger testes at 154 days of age or at 180 lb body weight tend to have higher percent spermatogenesis, but this is not a strong relationship. Faster gaining boars tend to have larger testes at 154 days of age but smaller testes at 180 lb body weight. Differences among boars in backfat was not associated with differences in testicular size or percent spermatogenesis. Selection for increased testicular size at 154 days of age should be effective. Such selection should show correlated improvements in testicular size at 180 lb body weight and percent spermatogenesis and should not be antagonistic to improvement in growth rate or backfat thickness. Direct selection for percent spermatogenesis would be somewhat less effective and may result in decreased growth rate and increased backfat thickness.

Table 1.—Least-squares means by breed and estimates of heritability for testicular traits

Item	Testicular volume (in^3) at 154 days	Testicular volume (in^3) at 180 lb	Percent[a] sperm
Breed means			
Spring farrowing			
Chester White	9.22[b]	9.95[b]	44.6[b]
Landrace	10.98[c]	10.13[b]	69.6[a]
Large White	11.47[c]	10.68[b]	61.3[a]
Yorkshire	11.47[c]	13.79[c]	48.9[b]
Fall farrowing			
Duroc	8.12[bc]	7.99[b]	49.6[c]
Hampshire	7.57[b]	8.60[b]	34.6[b]
Pietrain	9.28[cd]	13.18[c]	61.3[d]
Spot	9.82[d]	7.87[b]	45.5[c]
Heritability estimates	.55	.14	.22

[a]Percentage of tubules with complete spermatogenesis.
[bcd]Means with no common superscript differ significantly.
**$P < .01$.

Table 2.—Genetic (above diagonal) and phenotypic (below diagonal) correlations among testicular traits

Trait	154-day volume	180-lb volume	Percent sperm[a]
Volume at 154 days		1.12[c]	.58[c]
Volume at 180 lb	.54[b]		.86
Percent sperm[a]	.52[b]	.36[b]	

[a]Percent of tubules with active spermatogenesis.
[b]Significantly different from zero at $P < .01$.
[c]Significantly different from zero at $P < .05$.

Table 3.—Phenotypic (r_p) and genetic (r_g) correlations of testicular traits with daily gain and backfat

Trait	Daily gain r_p	Daily gain r_g	Backfat r_p	Backfat r_g
Volume at 154 days	.30[b]	.46	-.08	.14
Volume at 180 lb	-.36[b]	.26	.17[c]	.50
Percent sperm[a]	.07	-.48	-.04	.78

[a]Percent of tubules with active spermatogenesis.
[b]Significantly different from zero at $P < .01$.
[c]Significantly different from zero at $P < .05$.

Table 4.—Genetic correlations of testicular traits with age at puberty and litter size of gilts estimated by regression daughter on sire

Trait	Age at puberty	Litter size at birth
Volume at 154 days	.15	.03
Volume at 180 lb	.26	-.06
Percent sperm[a]	-.21	-.04

[a]Percent of tubules with complete spermatogenesis.

An Approach to Increase Litter Size

Kreg A. Leymaster, Ronald K. Christenson, and Larry D. Young[1]

Introduction

Litter size at birth is an important trait affecting production efficiency of swine. Despite recognition of its importance, average litter size has remained stable for decades. Approaches to increase litter size in commercial herds include the substitution of relatively prolific breeds for less prolific breeds and the exploitation of favorable heterosis effects through application of crossbreeding systems. These approaches depend upon existing genetic differences among breeds.

Selection is another genetic approach to increase litter size by directing improvement within breeds. Commercial and seedstock producers could benefit from selection progress. However, an experimental attempt to select for litter size was not successful in France. This failure arose partly from the complicated physiology of litter size, the expression of litter size only in females, and the relatively minor genetic regulation of litter size (heritability is about 10 pct).

To improve litter size it may be necessary to divide this complex trait into the component traits of ovulation rate, early prenatal mortality, and late prenatal mortality. The first component trait, ovulation rate, is the number of eggs (ova) released as determined by the total of corpora lutea on each ovary. Ovulation rate has been extensively studied in many nutritional, physiological, and genetic experiments It has a heritability of about 40 percent and can be increased by selection, based on a selection experiment with swine at the University of Nebraska. However, successful selection for ovulation rate did not markedly increase litter size. In fact, only about 12 percent of the increase in ovulation rate (due to selection progress) resulted in an additional pig. This discouraging result emphasizes the complex relationships that exist among litter size and the component traits of litter size.

The other component traits, early and late prenatal mortality (ova wastage), can be characterized as the total of missing pigs and mummies relative to ovulation rate. The majority (30 pct) of ova loss is recorded as embryos that die within the first 30 days of gestation (early prenatal mortality). An additional 10 to 20 percent loss of embryos and fetuses occurs throughout the remaining 84 days of gestation (late prenatal mortality).

The number of embryos at day 30 of gestation can be increased by embryo transfer, superovulation, and selection for ovulation rate. However, these extra embryos are lost during the last 84 days of gestation so that litter size is relatively unaffected. Therefore, embryo/fetal survival during gestation must be improved to take advantage of increased ovulation rate. Unfortunately, the study of embryo survival is complicated as some gilts do not experience a uterine challenge because ovulation rate may be less than the true uterine potential for litter size. Thus in normal gilts, observed litter sizes at birth may not accurately reflect uterine potentials.

Uterine potentials could be determined and possibly selected for if both uterine horns were challenged by more viable embryos than could be developed throughout gesta-

tion. This requires a consistent increase in the number of fertilized ova and, subsequently, the number of viable embryos per uterine horn. If a single ovary is removed, unilateral ovariectomy, the remaining ovary compensates by releasing ova equal in number to that of normal gilts with two ovaries. If an ovary and the adjacent uterine horn are both surgically removed, the number of ova in the remaining uterine horn is doubled. This procedure, unilateral hysterectomy-ovariectomy (UHO), may accomplish the experimental goal of beginning gestation with more ova and viable embryos than can be developed to farrowing. Therefore, gilts may have an opportunity to fully express uterine potentials as litter sizes at birth.

A study was conducted to evaluate UHO as an experimental model for measuring uterine potential. We propose that UHO would decrease the effects of ovulation rate on litter size and thus put more emphasis on accurate identification of differences among females in uterine potentials.

Procedure

Two hundred and eighty-six crossbred gilts were checked daily for estrus beginning at about 25 weeks of age. As gilts expressed estrus, they were assigned to control or UHO groups. Gilts in the UHO group were unilaterally hysterectomized-ovariectomized 8 to 12 days after the first observed estrus. A total of 233 gilts were bred during a 61-day breeding season. Only 120 gilts could be farrowed due to facility limitations. Therefore, bred gilts were assigned either to be slaughtered at about 86 days of gestation or to be farrowed. On about day 40 of gestation, gilts scheduled for farrowing were laparoscoped to determine ovulation rate. Forty-six control and thirty-nine UHO gilts were slaughtered at about 86 days of gestation. Ovulation rate and litter sizes and weights were determined. Valid data were analyzed for 45 Control-Slaughter, 70 Control-Farrow, 38 UHO-Slaughter, and 46 UHO-Farrow gilts.

Results

The 83 gilts that were slaughtered averaged 8.27 fully formed pigs as compared to 7.34 pigs for the 116 gilts that farrowed. The difference of .93 pigs was significant and represents late prenatal mortality occurring from 86 to 114 days (farrowing) of gestation.

Means of various traits for control and UHO gilts are given in Table 1. The control (two ovaries each) gilts did not differ significantly in ovulation rate from the UHO (one ovary each) gilts (12.11 eggs vs 11.87 eggs). UHO gilts had about twice as many mummies as control gilts. Control gilts produced significantly more fully formed pigs than did UHO gilts. However, UHO gilts produced 68 percent of the litter size observed for control gilts, despite having one-half of the uterine mass. This indicates that UHO gilts responded to the challenge of additional eggs in a single uterine horn per gilt. It also implies that control gilts could have 35 percent more pigs if ovulation rate was two-fold greater. Pigs from control gilts were significantly heavier at 86 and 114 days of gestation than pigs from UHO gilts.

Despite significantly lighter birth weights, pigs born to UHO gilts did not differ from pigs born to control gilts for postnatal survival, growth rate to 14 days, and 14-day

weight. These are encouraging results from an experimental standpoint and likely stem from the favorable effects of offspring from UHO gilts being reared with fewer littermates and, therefore, less competition.

The primary objective was to measure the effect of ovulation rate on litter size in control and UHO gilts. A method to test this objective is to estimate the proportion of an additional egg that is realized as a fully formed pig. In control gilts, averaged over both times of evaluation, .51 pigs resulted from an additional egg. The comparative value for UHO gilts was .24 pigs per egg. This difference was statistically significant and indicated that the UHO procedure did reduce the effect of ovulation rate on litter size. Since the effect of ovulation rate on litter size was reduced, then the effect of embryo survival must have increased. Therefore, UHO gilts were given a greater oppor-

tunity to express their potential for litter size as compared to control gilts. Further analyses indicated that embryo survival was about 1.7 times more important than ovulation rate in determining the litter size of control gilts that farrowed. This value increased to 2.2 by applying the UHO procedure, supporting the conclusion that the relative importance of embryo survival had increased.

The questions addressed are presently basic in nature and do not have immediate application to swine production. The research conducted was informative and knowledge gained may be used in future selection studies. We feel that unilateral hysterectomy-ovariectomy provides an advantageous setting to measure potential litter size and that opportunities to increase litter size by selection may be greater than previously recognized.

Table 1.—Means of control and UHO gilts

Trait	Control	UHO
Ovulation rate, eggs[a]	12.11	11.87
No. of mummies[a]	.22	.50
No. of fully formed pigs[a]	9.32	6.30
Individual pig weight, lb[a]	2.11	1.80
Postnatal survival to 14 days, percent	90.9	87.6
Growth rate to 14 days, lb/day	.36	.38
Individual 14-day wt, lb	8.14	8.03
No. alive at 14 days	7.61	4.61

[a]Values presented are averaged over data from slaughtered and farrowed gilts.

Energy Intake Restriction for Lean Growth Efficiency in Pigs

Gordon E. Dickerson and Howard S. Teague[1]

Introduction

Earlier research has shown that by appropriately restricting intake of a given diet, fat deposition can be reduced with little slowing of muscle and bone growth, provided intake of protein and other essential nutrients is not below levels required for the genetic lean growth potential of the stock. Thus, management control of the energy and protein intake of pigs may provide an alternative to genetic control of appetite relative to potential lean growth rate as a means of reducing waste fat in market pigs.

The experiment reported here was conducted to help answer five questions concerning restricting feed energy to control fat deposition in pigs:

1. To what extent can limiting only the energy component of feed intake reduce fat deposition without reducing rate of lean growth?
2. What is the most effective pattern for restricting energy intake during development?
3. What final weights will permit maximum reduction in cost of lean marketed from limiting energy intake?
4. How does genetic potential for lean growth relative to fat deposition influence answers to questions 1, 2, and 3?
5. What changes in grading and pricing of market pigs would be required for producers to benefit from limiting energy intake of market pigs?

Procedure

Six energy intake treatments were applied to four types of pigs from about 9 weeks of age to three age-constant and one weight-constant marketing endpoint (Table 1). The energy intake treatments were designed to compare full (ad lib) feeding of a corn-soybean meal diet with five degrees of reduced feed energy intake, without changing intake of protein, vitamins, and minerals (Table 2). Combinations of energy intake restriction to 87 or 74 percent of ad lib were applied separately to the growing (9 wk to age at 120 lb mean pig weight for the ad lib treatment) and the remaining finishing period on feed.

The pigs were all sired by the same set of Hampshire boars but from four groups of Duroc x Yorkshire crossbred sows differing in selection history of the parent lines. Three groups were crosses between pairs of Duroc and Yorkshire lines, both selected for either high backfat (H) or low backfat (L) or unselected (U) from 1954 to 1974. The fourth group was crosses of Duroc and Yorkshire parents sampled from industry purebred herds (P) in 1974.

Treatment comparisons were made within groups of litters (replicates) of the same breed group farrowed in the same week. In each replicate, four barrows and four gilts were assigned to each treatment, distributing pigs from each litter randomly across treatments. Comparisons of the ad lib 87/87, and 87/74 treatments were made in all nine replicates, but the 100/87, 100/74, and 74/74 treatments were evaluated only in the three replications of pigs from the unselected (U) dams. Desired restriction of energy intake was accomplished by hand feeding twice daily predetermined amounts of feed based on prior intake by pigs in the ad lib pen of the same replicate, adjusted weekly.

In each treatment-breed-replicate pen of four barrows and four gilts, one pig of each sex was assigned for slaughter at each of the three age-constant endpoints when pigs in the ad lib pen of that replicate reached mean liveweights of 220, 240, or 260 lb. The fourth pair in each pen was slaughtered when its mean liveweight reached 240 lb.

Results

Actual daily feed intakes (Table 3) were less than intended in weeks 1 to 4 for the 87/87 and 87/74 treatments but were compensated in the following period. The 120 lb mean liveweight for the ad lib fed pigs, which marked the beginning of the "finishing" period, occurred at about 7 weeks, and actual relative intakes corresponded closely to intended levels for each treatment. To reach the constant 240 lb slaughter weight endpoint, pigs on the more severely restricted intakes naturally needed to be fed longer after 105 days and thus consumed more feed relative to ad lib pigs than those slaughtered at a constant age.

Breed type of dam effects on performance to the three age-constant and the one weight-constant endpoints are given in Table 4. Pigs from all four types of dam were marketed at essentially the same liveweights, but market pigs from highfat crossbred dams had greatest feed intake, thickest backfat, highest dressing percentage, smallest loin eye area, least boneless ham, and slightly shorter carcass and legs. Pigs from lowfat and industry dams were both similar to control (U) in feed intake, but had less backfat, slightly longer leg and carcass, and more ham lean. Loin eye area was below controls for pigs from lowfat dams but highest of all for pigs from industry dams. Pigs of these diverse types were used in order to broaden the evaluation of restricting energy intake.

Restricting energy intake reduced backfat thickness (Table 5) at the average of the three slaughter ages (190 days) proportionally less than the restriction of energy intake (Table 3), even for the most severe restriction (87/74 and 74/74). However, backfat at the 240-lb weight endpoint was reduced only by severe restriction (100/74, 87/74, and 74/74) and generally less than in energy intake. Final liveweight at 190 days was reduced about 80 percent as much as energy intake, but feed/100 lb of gain to 190 days (Table 6) was reduced only for the 87/74 and 74/74 levels of restricted intake. Restriction reduced feed/gain to 190 days for pigs from industry, lowfat, and unselected dams but not for pigs from highfat dams.

The possible advantage of restricting energy intake would be to reduce fat deposition without limiting lean growth. Evidence from loin eye area (Table 5) indicates little effect of feed restrictions on muscle development to 190 days except for the maximum restriction in both growing and finishing periods (74/74). Boneless lean in ham was reduced proportionally a bit more than loin eye area by feed restriction, possibly because of less intermuscular fat in the boneless defatted ham from pigs on the restricted treatments. However, carcass and leg length also were reduced a little, up to -3 percent for the maximum restriction (74/74) from 9 weeks to market age of 190 days.

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Restricted pigs also dressed 2 to 3 percent lower at the same age than pigs fed *ad lib*.

The 74 percent restriction during finishing was more effective than 87 percent in reducing backfat and feed/gain (Table 6), without much more reduction in loin eye or separable lean ham. Restricting energy intake reduced estimated total weight of fat at the constant age endpoints at least three times as much as estimated carcass lean, and probably even more, because of lower fat content in separable lean from the restricted-fed pigs (Table 7).

Continuing the restricted-fed pigs to the older ages required to reach 240 lb liveweight (Table 5) did not reduce backfat as much at constant-age endpoints, except for the most severe restriction (74/74), increased leg and carcass length and boneless lean ham, and maintained loin eye area and dressing percentage. At the 240 lb weight endpoint, yield of separable lean actually was increased 4 to 6 percent by the 74 *vs* 87 percent energy restriction during the finishing period, while fat was reduced 10 to 14 percent (Table 7) and feed/gain also was lowered slightly (Table 6).

Table 1.—Numbers of replications and of pigs by type of dam and sex ($\male/\female$) for six energy intake treatments

Selection history of dams	No. replicates	Ad lib	100/87	100/74	87/87	87/74	74/74
			Intended energy intake, as percent of *ad lib* for growing/finishing period[a]				
Unselected (U)	3	12/12	12/12	12/12	12/12	12/12	12/12
Low fat (L)	2	7/8			8/7	10/6	
High fat (H)	2	6/7			8/7	6/9	
Industry (P)	2	7/8			8/8	6/10	
Totals		32/35	12/12	12/12	36/34	34/37	12/12

[a]Growing period was from about 9 weeks until pigs in *ad lib* treatment averaged 120 lb; finishing was remainder to slaughter.

Table 2.—Composition of diets and expected energy intake levels

	Growing[b]			Finishing[b]		
	100	87.5	75	100	87.5	75
			Intended feed intake, as percent of *ad lib* = 100			
Ingredients[a]						
Corn, ground, pct	75.3	68.0	58.4	82.3	76.2	67.9
Soybean meal, solvent, pct	22.2	29.1	38.2	15.2	21.0	28.7
Calculated						
Crude protein, pct	16.50	18.86	22.00	14.00	16.00	18.67
ME, Kcal/lb[c]	1,412	1,403	1,389	1,417	1,408	1,395
Energy intake/day pct of *ad lib*	100	86.9	73.8	100	86.7	73.8
Feed cost/lb[c]	5.2	5.5	5.8	5.0	5.2	5.5
Feed cost/day, pct of *ad lib*	100	92.5	83.6	100	91.3	82.6

[a]Minerals, salt, and vitamins were increased to offset the reduced feed intake.

[b]Growing = 9 weeks until *ad lib* pigs averaged 120 lb; finishing = remainder to slaughter.

[c]Based on 1,463 Kcal/lb and 4.4 cents/lb for corn; 1,402 Kcal/lb and 8.0 cents/lb for soybean meal.

Table 3.—Actual feed intakes by periods for six intended energy intake treatments[a]

Mean period fed	Actual (lb/day)	100/87	100/74	87/87	87/74	74/74
			Intended energy intake (growing/finishing), pct of *ad lib*			
0 - 28 days	3.25	100	96	79	79	78
28 - 49 days	5.43	102	103	90	90	79
49 - 77 days	5.75	92	77	90	78	77
77 - 105 days	5.75	86	74	88	75	75
105 - 113 days	6.28	82	74	82	73	68
105 - 126 days	5.88	89	76	94	79	76
105 - 143 days	6.13	88	76	88	74	76
105 days - 240 lb	5.88	84	82	92	78	82

[a]As percentage of the actual intake for the *ad lib* treatment.

Urea nitrogen in blood serum at 4, 7, 11, and 15 weeks of age (Table 8) was definitely lower in the leaner stocks on *ad lib* feeding, but was increased by breakdown of feed protein for energy and for fat storage by the restricted fed pigs, even in the more muscular pigs from industry dams. Free fatty acids in blood serum were higher in pigs from both highfat and industry dams than in those from unselected and lowfat dams, presumably for more fat deposition in highfat and possibly for higher maintenance in the leaner industry crosses. Restricting only energy intake increased blood fatty acids in highfat and unselected pigs but not in lowfat or industry pigs. These results support the evidence from body composition that restricting energy intake can divert feed protein from lean growth to breakdown for storage as body fat, especially by pigs with genetic potential for rapid fat deposition but slow lean growth.

Any economic advantage from restricting energy intake would depend upon the premium paid for leaner market animals and on the changes in feed and other costs per lb of lean pork in animals marketed. Total carcass lean, estimated as 3.86 x weight of separable lean ham (Table 7), increased with maximum restriction of energy intake by up to 5 or 6 percent in carcasses and 3 or 4 percent in liveweight. Actual increase in lean content of hams was undoubtedly greater than estimated, because of the smaller amounts of intermuscular fat in the separable lean from restricted-fed than from full-fed pigs. Thus, market price premiums based upon only actual lean pork content of restricted-fed pigs would need to be at least up to 10 or 12 percent higher for carcasses and up to 8 or 9 percent higher for liveweight.

Feed cost per pound of liveweight gain was actually increased up to 3 percent by restricting feed energy intake to age-constant endpoints (Table 9) because of reduced gains relative to maintenance and the higher protein content, and therefore price of feed required to maintain protein intake when feed intake is restricted (Tables 2 and 3). Costs/lb gain to the 240-lb slaughter weight were increased by up to 9 percent by restricting energy intake because the added feed costs for more days of maintenance feed (Table 5) exceeded the reduction in feed costs from less fat deposition.

Table 4.—Breed of dam effects on performance[a]

Trait	Highfat	Unselected	Lowfat	Industry	Reliability, pct[b]
Feed intake, lb	672	611	600	584	>10.0
Body weight, lb	222	225	228	227	>10.0
Backfat, in	1.79	1.40	1.28	1.19	< .1
Dressing, pct	75.7	73.7	74.1	74.4	>10.0
Carcass length, in	30.1	30.9	31.8	31.6	<1.0
Leg length, in	19.8	20.4	21.1	20.7	< .1
Untrimmed ham, lb	35.4	36.3	37.6	39.7	< .1
Boneless ham, lb	22.4	24.5	25.9	28.7	< .1
Loin eye area, in²	4.82	5.50	5.22	5.89	<10.0

[a]With equal weighting of the three age-constant and one weight-constant slaughter endpoints described in text.

[b]Percentage probability of breed differences this large from variation among replicates of same breed. All interactions of breed with slaughter endpoints or feed treatments were non-significant (>10.0 pct), except for feed intake of breed with age vs weight (<10.0 pct) and with three age endpoints (<1.0 pct).

Table 5.—Effects of limiting energy intake on body weight and carcass traits at market age (A) and weight (W) endpoints

Trait	Market[a] endpoint	Ad lib	100/87	100/74	87/87	87/74	74/74	Reliability, pct[b]
			Percent of *ad lib* energy (growing/finishing)					
Final live-weight, lb	A	240	224	211	215	206	198	< .1 T
	W	237	237	238	233	232	225	< .1 (A-W)
		(189)[a]	(205)[a]	(210)[a]	(209)[a]	(217)[a]	(217)[a]	< .1 Tx(A-W)
Backfat, in (mean, midline at 1st, last, last lumbar vertebra)	A	1.54	1.38	1.30	1.34	1.26	1.22	< .1 T
	W	1.52	1.47	1.36	1.53	1.33	1.21	< 5.0 (A-W)
Dressing, percentage	A	75.4	73.8	72.6	73.6	73.4	73.1	< .1 T
	W	75.5	74.5	73.4	74.7	75.1	76.2	< 10.0 (A-W)
Carcass length, in	A	31.3	30.9	30.6	30.7	30.5	30.5	< .1 T
	W	31.0	31.5	31.0	31.3	31.4	31.1	< 1.0 (A-W)
Leg length, in	A	20.5	20.4	20.3	20.4	20.2	19.9	<1.0T, <.1 (A-W)
	W	20.4	20.2	20.5	20.4	21.2	20.9	<.1Tx (A-W)
Untrimmed ham, lb	A	38.9	36.6	34.3	35.5	34.2	32.9	<.1T, <.1 (A-W)
	W	39.2	38.9	39.9	38.4	39.8	39.1	<.1Tx (A-W)
Separable lean in ham, lb	A	25.8	25.0	23.7	24.5	23.8	23.0	<.1T, <.1 (A-W)
	W	26.1	26.2	27.1	26.1	27.8	27.1	<.1Tx (A-W)
Loin eye area, in[b]	A	5.41	5.33	5.11	5.36	5.26	4.71	< 5.0 Tx (A-W)
	W	5.56	5.01	5.30	5.14	5.59	5.39	

[a]At ages when *ad lib* pigs in a replicate reached mean weights of 220, 240, or 260 lb (A) and at 240 lb (W). Days of age at W (240 lb) endpoint are shown ( ) below the mean final weight for each treatment.

[b]Percentage probability of chance differences this large from sampling errors. There were no significant breed differences in treatment or in (A-W) effects.

Total cost per pound of liveweight marketed at age end-points, including all sow and the non-feed pig costs, actually was increased up to 10 percent by restricting energy intake, mainly because the sow and non-feed costs must be charged to fewer pounds of liveweight marketed (Table 9). As expected, feed cost per pound of gain increased with age at marketing. However, when sow and pig non-feed costs and total pig weights were included, total cost/lb of liveweight marketed did not increase between 176 and 206 days of age, because the increased pig feed cost/lb of gain was offset by spreading sow costs over more weight marketed. When pigs were fed to a constant 240-lb market weight, restricting energy intake still increased total cost/lb liveweight marketed up to 9 percent, because of the longer feeding period, even though the sow costs/lb marketed were not increased.

Total cost per pound of estimated carcass lean to the age endpoints was not reduced by restricting energy intake (Table 9), because the resulting higher lean content of liveweight (Table 7) was only enough to offset the higher total cost/lb of liveweight from restricted-fed pigs. When restricted pigs were marketed at 240 lb liveweight, only the most severe restriction during the finishing period (100/74, 87/74, and 74/74) produced cost/lb carcass lean as low as that for pigs fed *ad lib*.

This experiment suggests little economic justification for restricting energy intake to reduce excess fat deposition in growing/finishing pigs, even if pigs could be sold strictly on the basis of their yield of carcass lean. Under the present partial premiums for higher yields of carcass lean in liveweight, restriction of energy intake to either age or weight endpoints definitely would not be profitable for

Table 6.—Effects of limiting energy intake (T) on feed/gain (lb/100 lb), by breed (B) of dam and market age (A) and weight (W) endpoints

Breed of dam[a]	Market endpoint[a]	Percent of *ad lib* energy (growing/finishing)					
		Ad lib	100/87	100/74	87/87	87/74	74/74
High fat	A	352			364	345	
	W	349			377	359	
Unselected	A	324	319	314	314	305	303
	W	330	347	316	339	332	332
Low fat	A	311			310	293	
	W	309			333	316	
Industry	A	309			299	280	
	W	305			320	301	
All[b]	A	323	320	315	320	304	305
	W	320	344	313	341	326	329

[a]See text and Table 5 definitions for breed of dam and for constant age and weight endpoints.

[b]Probability of chance differences this large from sampling errors was <0.1 pct for T or for (A-W), <10.0 pct for B and <1.0 pct for effects of B on T responses.

Table 7.—Effects of limiting energy intake on carcass lean and fat at constant age (A) and weight (W) endpoints and on corresponding relative values for carcass and liveweight based on lean content only

Variable	Market endpoint	Percent of *ad lib* energy (growing/finishing)					
		Ad lib	100/87	100/74	87/87	87/74	74/74
Separable lean in carcass, lb[a]	A(190 days)	99.5	96.6	91.4	94.7	91.8	88.9
	W(240 lb)	100.9	100.6	104.7	100.7	107.1	104.6
Fat + bone in carcass, lb	A(190 days)	81.4	69.1	61.5	63.9	59.5	55.7
	W(240 lb)	78.1	75.6	70.4	73.4	67.2	67.1
Carcass lean, pct of carcass[a]	A(190 days)	55.0	58.3	59.8	59.7	60.7	61.5
	W(240 lb)	56.4	57.3	59.8	57.8	61.4	61.0
pct of liveweight[a]	A(190 days)	41.5	43.1	43.3	44.0	44.6	45.0
	W(240 lb)	42.5	42.7	44.0	43.2	46.2	46.6
Relative value/lb, pct of carcass	A(190 days)	100	106	109	109	110	112
	W(240 lb)	100	102	106	103	109	109
pct of liveweight	A(190 days)	100	104	105	106	107	108
	W(240 lb)	100	100	103	102	108	109

[a]Using 3.86 x weight of separable lean in hams, based on a 1975 regional study of pork carcass evaluation systems (Fahey et al., 1977, J. Anim. Sci. 44:8).

pork producers if it increased cost/lb of liveweight marketed by 4 to 12 percent as found in this study.

Even if market hog prices fully reflected their lean meat value, the present results would not encourage energy intake restriction as a method for reducing total costs/lb of carcass lean marketed. The alternative of increasing genetic potential for faster lean growth and reduced fat deposition would seem a far more promising one.

In short, results from this experiment showed that:

1. Restricting energy intake without limiting other nutrients reduced deposition of fat much more than lean but increased total costs/lb of liveweight up to 9 or 10 percent, and did not reduce total costs/lb of carcass lean marketed at either age-constant or weight-constant endpoints.

2. The most nearly cost-effective patterns of restricting energy intake during the growing/finishing periods for marketing at a constant 240 lb liveweight were those for 100/74 or 87/74 percent of ad lib intake, which did not reduce total cost/lb of lean. Marketing restricted pigs of lighter weights at the same age as pigs fed ad lib also failed to reduce total costs/lb of lean.

3. Total costs/lb of liveweight differed little between 176- and 206-day marketing, but costs/lb of carcass lean were less for the 206-day marketing.

4. Pigs with genetic potential for rapid lean growth and slower fat deposition responded better to limited energy intake than fatter, less muscular types of pigs.

5. Grading and pricing of market pigs on lean meat value seems unlikely to justify management restriction of energy intake for market pigs, but would provide incentive for developing genetic strains capable of more efficient lean growth under ad lib feeding.

Table 8.—Effect of limiting energy intake on constituents of blood serum and by breed of dam[a]

| Constituent | Breed of dam | Percent of ad lib energy (growing/finishing) | | | | |
		Ad lib	100/74	87/87	87/74	Average
Urea nitrogen, mg/liter	High fat	372	---	428	504	430[b]
	Unselected	301	334	350	406	348
	Low fat	248	---	345	367	316
	Industry	249	---	307	297	280
	Average[b]	293	303	358	394	343
Free fatty acids, meq/liter	High fat	332	---	394	447	393[b]
	Unselected	219	259	236	302	254
	Low fat	193	---	127	225	183
	Industry	433	---	476	365	426
	Average	294	319	308	335	314

[a]Blood samples were taken at 4, 7, 11, and 15 weeks of age from 12 pigs per feed intake treatment and type of dam, except that only pigs from unselected dams were sampled for the 100/74 treatment.

[b]<0.1 percent probability of chance occurrence.

Table 9.—Effects of limiting energy intake on feed cost/lb gain, and on total cost/lb of liveweight or of separate carcass lean, by market endpoints

| Variable | Market endpoint | Percent of ad lib energy (growing/finishing) | | | | | |
		Ad lib	100/87	100/74	87/87	87/74	74/74
Feed cost/lb gain/cents	A(176 days)	15.9	16.7	16.5	16.5	16.4	16.4
	A(189 days)	16.5	17.0	16.5	16.9	16.9	16.9
	A(206 days)	17.1	17.6	17.9	18.0	17.6	17.9
	W(240 lb)	16.5	17.5	16.8	18.2	18.0	17.9
Total cost/lb liveweight[b]	A(176 days)	32.1	33.7	34.7	34.4	35.1	35.9
	A(189 days)	32.0	33.4	33.8	33.8	34.7	35.6
	A(206 days)	31.8	33.1	34.9	34.4	34.8	35.9
	W(240 lb)	32.0	33.4	33.1	34.5	34.9	35.3
Total cost/lb carcass lean, cents	A(176 days)	78.6	81.5	81.1	79.0	79.0	78.7
	A(189 days)	75.2	75.0	79.1	77.4	78.3	82.0
	A(206 days)	77.1	76.2	78.0	77.4	77.0	77.9
	W(240 lb)	75.2	78.1	75.3	80.0	75.6	75.9

[a]Based on 4.4 cents/lb corn, 8.0 cents/lb soybean meal.

[b]Adding $30/pig + 10 cents/day on feed.

The Above-Maintenance Feed Energy Costs of Protein and Fat Deposition in Pigs

Michael W. Tess, Gordon E. Dickerson, Calvin L. Ferrell, John A. Nienaber, and Jong-Tseng Yen[1]

Introduction

Reduction of feed energy inputs per unit of lean pork produced is an important means of improving production efficiency. Understanding the partition of feed energy use within the body and the energetic efficiencies of the various body functions allows more accurate prediction of effects on feed energy requirements from potential genetic changes in the rate and chemical composition of growth in pigs.

In the absence of climatic stress, the energy (ME) costs associated with maintenance (M), protein deposition (P), and fat (F) deposition are the primary determinants of feed energy requirements in growing pigs. The purpose of this study was to estimate the above-maintenance metabolizable energy costs per unit of protein deposition (b_P), and fat deposition (b_F) from an experiment with full-fed pigs of genetic stocks that differed widely in body composition and growth rate.

Procedure

Ten sets of three littermate barrows from each of three genetic stocks (Beltsville highfat and lowfat Duroc-Yorkshire composites and a Hampshire x Large White cross) were used in a comparative individual feeding calorimetry and slaughter experiment. At 10 weeks of age, one pig from each set was assigned to initial slaughter. The remaining two pigs were individually full-fed a 16 percent crude protein corn-soybean meal diet for 7 or 14 weeks. Prior to slaughter, fasting heat production (FHP) was estimated for each pig in an open-circuit calorimeter. The digesta-free body of each pig was analyzed chemically for protein, fat, water, and ash content.

To determine the metabolizable energy content of the diet used for each of the three stocks during each feeding period, a conventional nitrogen and energy balance experiment was conducted concurrently with the main experiment. Five additional barrows from each of the three lines were used. Collections of feces and urine were made from each pig during two 4-day periods at approximately 13 and 20 weeks of age.

Several methods were used to find the best equation to describe the utilization of metabolizable energy by growing pigs. The basic form of the equation was assumed to be:

$$ME_I = b_M (\Sigma M_i) + b_P \Delta P + b_F \Delta F$$

where

ME_I = metabolizable energy in feed intake, in Megacalories (Mcal)

M_i = the amount of lean (lb$^{.85}$) or of liveweight (lb$^{.75}$) maintained on the ith day. ΣM_i = sum of M_i for a period.

b_M = regression coefficient relating ME_M to M_i.

$b_M (\Sigma M_i) = \Sigma ME_M$, the total maintenance feed energy for a period of days.

b_P, b_F = the ME-costs/lb of protein deposition (ΔP) and fat deposition (ΔF), respectively, in excess of ΣME_M.

Lean (lb$^{.85}$) was found to be the best predictor of ME_M, based upon analyses of the calorimetry data, as was discussed in earlier reports. Metabolic liveweight (lb$^{.75}$) was used for comparison since it is commonly used in nutritional research to relate ME_M to liveweight.

Body composition at the start of the feeding period was predicted from the composition of the sibs slaughtered at the beginning of the feeding period.

Results

Regressions in the form of equation (1) were fitted to the data from (10 to 17) + (17 to 24) weeks to minimize the dependence between lean$^{.85}$ or liveweight$^{.75}$ maintained and amount of protein deposited, ΔP (Table 1). Standard errors for the fitted coefficients were low and the accuracy of prediction was high ($R^2 = .94$). Estimates of b_M were higher than many literature reports and may reflect the fact that the pigs were individually fed in rather large pens, allowing more activity.

To evaluate the generality of the estimated maintenance requirement ($b_M M_i$) for all of the data, the intake data was adjusted for ME_M (i.e., $ME_I - ME_M$), assuming ME_M (kcal/day) to be .059 lean lb$^{.85}$ or .090 liveweight lb$^{.75}$. The coefficients b_P and b_F were then estimated again from the adjusted data (Table 1).

Estimates of b_P and b_F were quite similar to those obtained from the (10 to 17) + (17 to 24) week data and the accuracy of prediction was very good ($R^2 = .98$ where 1.0 is perfect accuracy). Estimates of b_P and b_F were not affected in a systematic way by the age of the pigs. In both data sets, estimates of b_F were lower when ME_M was predicted from liveweight$^{.75}$ than when ME_M was predicted from lean weight$^{.85}$. Liveweight$^{.75}$ is a commonly used predictor of ME_M, yet our research has shown that ME_M is predicted more accurately from lean mass. These results suggest that estimates of feed energy cost for fat deposition (b_F) are biased downward when ME_M is predicted from liveweight, because ME_M of fatter pigs is overestimated from liveweight$^{.75}$. The corresponding bias in estimated energy costs for body protein deposition (b_P) was much smaller but in the opposite direction.

Alternative regression methods showed that estimates of b_P are very sensitive to prior estimates and/or assumptions relative to maintenance energy (ME_M). In fact, over continuous feeding intervals, energy use may be predicted well from only ΔF and the lean mass maintained. However, predictors such as those based on lean mass, ΔP and ΔF (in Table 1) are more interpretable, because they more clearly separate the effects of protein and fat deposition from maintenance. Such information is more useful in predicting the effects of genetic changes in proportion of body protein vs fat deposition on feed costs per unit of lean pork produced.

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Table 1.—Equations for predicting total daily feed energy intake (ME_I in Mcal) from regressions on metabolic body size (b_M x M_i), protein deposition (b_P x $\triangle$ P), and fat deposition (b_F x $\triangle$ F)

Data set and metabolic size (M_i in lb)[a]	b_M (Mcal/M_i)	b_P (Mcal/lb)	b_F	Accuracy[b] (R^2)
(10 to 17) + (17 to 24) weeks				
M_i = Lean$^{.85}$	.059[b]	5.31	6.95	.94
Liveweight$^{.75}$	.090[b]	5.22	5.58	.94
All data				
M_i = Lean$^{.85}$	.059	4.97	7.36	.98
Liveweight$^{.75}$	.090	5.43	5.65	.98

[a]Coefficients of M_i derived from (10 to 17) + (17 to 24) week data were considered most accurate and used in equations for all data. See text.

[b]R^2 = squared correlation of observed with predicted ME_I. Fraction of total variation in ME_I due to deviations from predicted values = 1 - R^2.

Effect of Breed, Crossbreeding System, and Breed Role on Costs of Pork Production and on Breeding Objectives

Gary L. Bennett, Michael W. Tess, Gordon E. Dickerson, and Rodger K. Johnson[1,2]

Introduction

Choice of crossbreeding system and of the breeds best suited to each breed role in the system can have an important influence upon production costs per unit of pork output. Knowing how heterosis affects efficiency of each crossbreeding system is useful in choosing among systems. Knowing the relative importance of different performance traits for each breed role (i.e., as dams or sires of market pigs) in each breeding system is helpful in selecting among existing breeds for each role, and also in developing efficient within-breed selection procedures for breeds intended for different roles in the production system.

This summary report presents results from a computer simulation evaluation of (1) efficiency for alternative crossbreeding systems, and (2) relative importance of different performance traits for different breed roles in crossbreeding systems. Total cost per unit of liveweight or of carcass lean output was the criterion of system efficiency.

Procedure

Economic efficiency of pork production was simulated

for six breeding systems and for assumed performance characteristics of six alternative breeds. Systems compared included purebreeding (PURE); two-breed specific (2SPEC), backcross (2BACK), and rotation (2ROTA) crosses; and three-breed specific (3SPEC) and rotation (3ROTA) crosses. Percent of the total number of sows needed to produce replacement gilts and boars for each breed role in the systems is shown in Table 1.

A bio-economic computer model of pork production was used to predict total costs/lb of live- or of lean weight from each combination of breeds in each breeding system. A maximum of three litters/sow, 28-day weaning of litters, no more than 70 percent of available gilts and boars used as replacements, and a 1/20 ratio of boar/gilt replacements was simulated. Sow and market pig weights were combined after discounting sow weights by 13 percent for liveweight and 21 percent for lean output. Costs of both live (LIVE$WT) and carcass lean (LEAN$WT) weight were calculated for pigs marketed at 220 lb liveweight, but cost of lean was also calculated for marketing at the average 185-day weight (LEAN$AGE).

Changes in performance traits were evaluated for each breed role. Differences in average costs of production, including replacements, from changing performance traits were multiplied by breed differences. The average breeding value of any cross was proportional to its breed composition, plus heterosis proportional to expected level of heterozygosity.

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[2]Results reported in Journal of Animal Science 56:801-813, 1983.

Table 1.—Percentages of all sows and breed composition of replacement male and female populations and of market litters for six breeding systems[a]

Breeding system	Replacement populations for		Market pigs	Breed role	
	Males	Females		Paternal	Maternal
Purebred	1.6A	31.3A	67.1A	A	A
Specific:					
Two-breed (2SPEC)	.5A/1.1B	31.3A	67.1(B x A)	B	A
Backcross (2 BACK)	1.3A/.3B	9.5A/20.2(B x A)	$68.7A \times (\frac{B+A}{2})$	A	A Primary
Three-breed (3 SPEC)	.2A/.3B/1.1C	9.5A/20.2(B x A)	$68.7C \times (\frac{B+A}{2})$	C	A Primary B Secondary
Rotation:					
Two-breed (2ROTA)	.8A/.8B		$98.4B \times (\frac{2A+B}{3})$[b] or A $\times (\frac{2B+A}{3})$	A,B	A,B
Three-breed (3ROTA)	.5A/.5B/.5C		$98.4C \times (\frac{4B+2A+C}{7})$,[b] A $\times (\frac{4C+2B+A}{7})$, or B $\times (\frac{4A+2C+B}{7})$	A,B,C	A,B,C

[a]Breed of sire followed by breed of dam (e.g., A X B).

[b]Includes 31.3 percent of crossbred matings used to produce gilt replacements.

The breeding values assumed for seven primary traits of six U.S. breeds (Table 2) were used only to illustrate potential breed effects on production system efficiency. These breeding values were estimated from a combined analysis of crossbreeding experiments at the Iowa and Oklahoma Experiment Stations and may not be closely representative of other samples from these breeds. The range in breeding values was relatively narrow (3 or 4 pct) for age at puberty and for litter size at birth; wider for age at 220 lb (9 pct) and milk production (11 pct); but considerably greater for fertility (15 pct), preweaning survival (20 pct), and body fat at 220 lb (24 pct). These breed ranges for different traits influence their relative importance in choosing breeds for specific roles in production systems. All trait changes were evaluated for marketing at 220 lb liveweight, but only days to 220 lb was evaluated for marketing at mean 185-day weight because earlier research had shown that 185-day marketing had little influence on evaluation of other traits.

Results

Crossbreeding systems reduced average non-feed costs much more than feed costs, especially for costs of carcass lean marketed at mean 185-day weight (Table 3). Reductions in total costs below those for purebreeding also were greater for lean at LIVE$AGE than for either LIVE$WT or LEAN$WT. These relationships applied to each of the five crossbreeding systems evaluated. For example, reductions in feed, other, and total costs for three-breed rotation (3ROTA) crossbreeding were -4.2, -12.1, and -7.9 percent for LIVE$WT; -3.8, -11.7, and -7.5 percent for LEAN$WT; but -2.5, -17.2, and -9.5 for LEAN$AGE. Average reductions (for all possible breed combinations of each crossing system) ranked in the same order for feed, other and total costs, and for all three measures of efficiency (LIVE$WT, LEAN$WT, and LEAN$AGE). Costs were reduced only slightly more for 3ROTA than for 3SPEC, but both were better than 2ROTA and 2BACK, and cost reduction for 2SPEC was one-half or less that for 3ROTA and 3SPEC.

Table 2.—Sample breeding values for seven performance traits of six breeds [a]

Traits	D	H	Y	L	S	C	Units	pct
				Breeds			Range	
Age at puberty, days	192	186	190	185	185	190	7	3.7
Fertility, pct	80	87	74	75	82	87	12	15
Litter size born	10.0	9.5	10.6	9.4	8.0	11.3	3.3	3.4
Milk production, pct of mean	94	104	99	105	98	100	11	11
Preweaning survival, pct	68	61	71	75	73	65	14	20
Days to 200 lb wt	183	193	186	194	186	200	17	9
Body fat at 220 lb wt								
Carcass, pct	35.3	29.7	33.9	37.9	36.6	33.5	8.2	24
Back, in	1.15	.90	1.09	1.27	1.21	1.07	.38	34

[a]Estimated in crossing experiments at Iowa and Oklahoma Experiment Stations. Breeds are Duroc (D), Hampshire (H), Yorkshire (Y), Landrace (L), Spot (S), and Chester White (C).
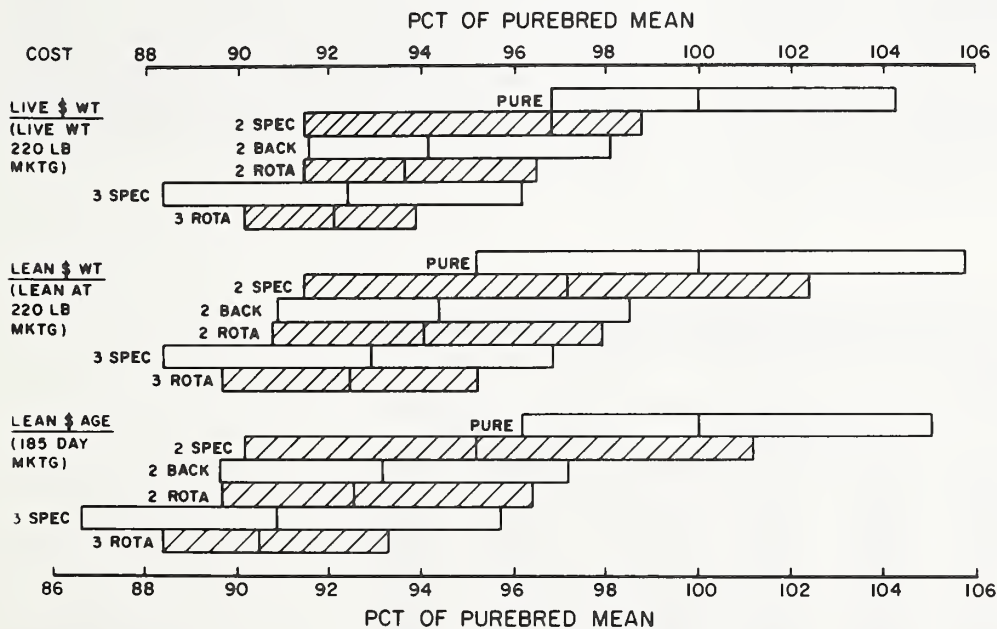

Figure 1—Range from lowest to highest cost breed combinations within each system as a percent of average purebred production cost.

Differences in costs per pound among breed combinations within breeding system were larger for purebreeding and two- and three-breed specific crossbreeding than for two-breed backcrossing or rotation crossing, and breed combination differences were smallest for three-breed rotation crossing (Fig. 1). Systems which utilized superior maternal breeds to produce sow replacements and superior growth-carcass breeds to sire market pigs made best use of difference among the six breeds. The best 3SPEC combinations were nearly 2 percent better than the best 3ROTA breed combinations, even though the average for all breed combinations was slightly better for 3ROTA than 3SPEC systems.

Relative importance of traits in choosing breeds differed considerably between breeding systems and particularly between specific breed roles in a system. In systems where market animals and sow replacements had similar breed composition (PURE, 2ROTA, 3ROTA, and 2BACK), the maximum percentage in cost reductions was greatest for breed differences in litter size (-10 pct), pig viability (-7 pct), and sow fertility (-3 pct), but small for milk and earlier puberty (<1 pct). Breed differences in body fat were as important as those in litter size for cost/lb of lean (-10 pct), but reduced body fat actually increased costs/lb of liveweight (+2 pct). Faster breed growth rate was about as important as sow fertility (-3 pct) for cost of lean when pigs were marketed at mean 185-day weight but contributed little (<1 pct) when marketing was for liveweight or lean at constant 220 lb liveweight. Relative importance of traits for breeds used in rotation crossing and as granddam and sire in backcrossing was very similar to that for purebreeding.

Compared to pure, rotational, and primary backcross breed roles, maximum percent cost reductions for difference, among breeds used only to produce sow replacements in specific two- or three-breed crossing or backcrossing systems, were sharply increased for superior litter size (-22 pct), sow fertility (-8 pct), and milk production (-3 pct). Differences in cost were increased to a lesser degree for better pig viability (-10 pct) and less body fat (-12 pct for LEAN$WT and LEAN$AGE), and unchanged for faster growth rate (-3 pct for LEAN$AGE). The relative importance of traits among purebreds and among maternal grandsire breeds was similar in 3SPEC and 2BACK crosses.

The only breed difference for sires of market pigs contributing to important reduction in cost/lb of both live- and lean weight in specific crossing (2SPEC and 3SPEC) systems was pig viability (-5 pct). Sire-breed superiority in leanness was even more important for cost/lb of lean (-7 pct) but not for cost/lb of liveweight (+1 pct). Sire breed superiority in growth rate was important only when marketing lean at mean 185-day weight (-3 pct), as was true for other breed roles. Clearly, superiority in both reproduction and growth-carcass traits is important for breeds used for sow replacements, but only superiority in viability, leanness, and growth rate is important for terminal-sire breeds.

The relative importance of different performance traits for selecting within breeds also would differ with the intended breed roles in the production system. The reported relative importance of traits was strongly influenced by the ranges in breeding value for each trait that were assumed among the six breeds (Table 2). For selection within breeds, relative importance of traits would depend on the scale of within-breed rather than between-breed genetic variation. Relative emphasis for within-breed selection also would be affected by heritability of the traits and the correlations among them.

Expected effects of breeds in alternative breeding systems and breed roles on costs/lb of either carcass lean marketed at average 185-day weight (LEAN$AGE) or of liveweight marketed at 220 lb (LIVE$WT) are shown in Table 4. Breed differences for similar crossbreeding roles were averaged because they were so nearly alike. In fact, breed rankings differed primarily in degree between general purpose roles (PURE, 2BACK, 2ROTA, and 3ROTA), maternal grandsire (2BACK and 3SPEC), dam (2SPEC), and maternal granddam (3SPEC) roles. However, breed rankings did change markedly between terminal sire (Paternal 2SPEC and 3SPEC) and other breed roles, especially for breeds differing most in reproductive traits (e.g., Chester White and Spot).

Breed rankings changed even more between marketing of lean at average 185-day weight (LEAN$AGE) or of liveweight at 220 lb (LIVE$WT), especially for breeds differing greatly in leanness (e.g., Hampshire and Landrace). Breeds moderately superior in most reproductive traits as well as in growth and leanness (e.g., Yorkshire) ranked reasonably well for LIVE$WT marketing and even better for LEAN$AGE marketing in a terminal sire as well as any other role. Other breeds ranked well only in maternal or general purpose (e.g., Chester White) or paternal (e.g., Spot) breed roles, or only when the market premium for leanness was high (LEAN$AGE; e.g., Hampshire) or low (LIVE$WT; e.g., Landrace).

Table 3.—Estimated feed, other, and total costs of pork production for purebreds and cost reductions for alternative crossbreeding systems (average for all combinations of six breeds)[a]

System	LIVE$WT ($/lb livewt at 220 lb)			LEAN$WT ($/lb lean wt at 220 lb)			LEAN$AGE ($/lb lean wt at 185 days)		
	Feed	Other	Total	Feed	Other	Total	Feed	Other	Total
PURE	.233	.209	.442	.446	.402	.847	.446	.402	.847
2SPEC	-.005	-.009	-.014	-.008	-.016	-.024	-.004	-.036	-.040
2BACK	-.007	-.019	-.026	-.012	-.035	-.047	-.009	-.049	-.058
2ROTA	-.008	-.020	-.028	-.013	-.037	-.050	-.009	-.054	-.063
3SPEC	-.010	-.024	-.034	-.016	-.044	-.060	-.011	-.066	-.077
3ROTA	-.010	-.025	-.035	-.017	-.047	-.064	-.011	-.069	-.080

[a]See Table 1 for definitions of breeding systems.

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Table 4.—Predicted breed effects on costs ($/lb) of carcass lean marketed at mean 185-day weight (LEAN$AGE) or of liveweight marketed at 220 lb liveweight (LIVE$WT) for alternative breed roles in production systems, as a percentage of mean purebreeding costs for six breeds[a]

System/ breed role	Basis	Breeds[b]					
		D	H	Y	L	S	C
Purebreeding	LEAN$AGE	.24	-2.23	-3.77	3.75	4.96	-3.06
	LIVE$WT	.39	4.32	-2.21	-1.95	2.68	-3.22
2BACK Primary, 2ROTA, 3ROTA	LEAN$AGE	.13	-2.00	-3.05	3.28	3.92	-2.37
	LIVE$WT	.10	3.60	-1.77	-1.46	1.87	-2.33
Maternal							
2BACK Secondary and 3SPEC Grandsire	LEAN$AGE	.25	-2.01	-3.64	4.13	6.31	-5.15
	LIVE$WT	.14	4.00	-2.32	-.86	4.11	-5.05
2SPEC Dam	LEAN$AGE	1.78	-3.61	-3.78	4.76	8.94	-8.21
	LIVE$WT	1.87	4.00	-1.95	-1.87	6.08	-8.09
3SPEC Granddam	LEAN$AGE	1.56	-3.75	-3.98	5.75	10.98	-10.89
	LIVE$WT	1.40	3.78	-2.34	-.33	8.13	-10.59
Paternal							
2SPEC, 3SPEC	LEAN$AGE	-.20	-.97	-1.95	1.34	-.32	2.05
	LIVE$WT	-.01	3.02	-.87	-2.19	-1.61	1.66

[a]To permit easier comparison of breed rankings for different breed roles, effects on costs were divided by the fractional contribution of each breed role to market pig genotype (e.g., by .75 for 2BACK primary, .25 for 3SPEC maternal, etc.)

[b]Positive values indicate an increase in cost; negative values, a decrease in cost.

Postweaning Estrus in First-Litter Sows of the Duroc, Hampshire, Pietrain, and Spot Breeds

Joe Ford, Ronald K. Christenson, John Klindt, and William P. Switzer[1]

Introduction

Anestrus after piglets are weaned from first-litter sows continues to be a problem in some swine production enterprises. A number of factors, including time of the year, parity, weight loss during lactation, and breed, have been associated with postweaning anestrus. However, an explanation of how these factors interact to influence estrous activity in sows is lacking. We conducted four experiments to evaluate the relationship of postweaning estrous activity to feed intake, weight change, serum hormone concentrations, and breed.

Procedure

We utilized gilts from four breeds (Duroc, Hampshire, Pietrain, and Spot) with each breed originally comprised of a sample of approximately nine different sire blood lines. In all studies, gilts were bred at 8 to 10 months of age, and litters were weaned after a 4-week lactation. Gilts farrowed in May-June or September-October, with the majority of females farrowing during the later season. During lactation, sows were fed *ad libitum* a diet calculated to contain 1.38 Mcal of metabolizable energy per pound and 15.6 percent crude protein. After weaning, daily estrous evaluation of sows was conducted with mature boars.

Results

In two of the experiments, body weight lost during lactation was determined. Weight lost was defined as the gilt's weight on day 110 of gestation minus her weight at the completion of lactation. Weight lost and number of live piglets weaned were 30.8 lb and 6.6 pigs for 45 first-litter sows detected in estrus within 10 days after weaning and 27.9 lb and 5.9 pigs for 34 sows not detected in estrus by day 10. Feed consumption during lactation was monitored in one experiment and averaged 9.2 lb/day for 8 sows detected in estrus and 8.6 lb/day for 18 sows not detected in estrus by day 10. Both weight lost and daily feed consumption were less than expected from our studies with other breeds, but neither was associated with postweaning anestrus.

Prolactin and cortisol are hormones that are secreted during some types of stress. Blood samples were collected through indwelling jugular catheters from 12 estrous and 11 anestrous sows during the first 7 days after weaning. The concentrations of prolactin and cortisol were not greater in the blood of anestrous sows. Other serum factors that were observed to be similar in estrous and anestrous sows were calcium, phosphorus, thyroxine, and triiodothyronine. Thus, the concentrations of the blood constituents that were evaluated were not related to the anestrous condition.

The one trait that showed an association with postweaning estrous activity was breed (Table 1). Under our management conditions and with the sampling of each breed represented in our herd, we observed estrus by day 10 after weaning in a greater percentage of Pietrain and Spot than in Duroc and Hampshire sows. Because two published studies indicate significant effects on postweaning estrous activity due to the farm on which the data were collected, it cannot be assumed that these breeds would perform similarly under different management conditions. We were unable to identify a factor other than breed that was associated with the occurrence of postweaning anestrus.

[1]Ford is a research physiologist and Christenson is the research leader, Reproduction Research Unit, MARC; Klindt is a research physiologist, Meats Research Unit, MARC; and Switzer is the Associate Dean of Research, Department of Veterinary Medicine, Iowa State University of Science and Technology.

Table 1.—Breed differences for postweaning estrous activity in first-litter sows[a]

Breed	Number of sows evaluated	Percentage detected in estrus by day 10 after weaning
Duroc	112	32
Hampshire	114	39
Pietrain	29	93
Spot	95	77

[a]Data from four experiments were combined; Pietrain sows were evaluated in only two of the four.

Endocrine Control of Sexual Behavior in Boars

Donald G. Levis and Joe Ford[1]

Introduction

Lack of sexual behavior in boars is a serious problem for some commercial and purebred swine enterprises. It is not uncommon for commercial pork producers to purchase 25 to 30 percent more boars than actually needed since many boars are not sexually motivated to mate sows by 9 to 12 months of age. Boars of this type are costly to the swine industry, regardless of whether females are hand mated or pen mated. Boars expressing little or no male sexual behavior are especially a problem when pen mating, as pork producers generally do not evaluate boars for sexual behavior prior to use. Two recent surveys have revealed that about 80 percent of pork producers still pen mate sows.

A better understanding of why mature boars do not express adequate sexual behavior is needed in the swine industry. At present, little is known about the mechanisms whereby hormones from the testis regulate certain areas of the brain to stimulate male sexual behavior in boars. A general hypothesis is that mature boars that express little or no male sexual behavior have not had the brain tissue exposed to the appropriate testicular hormone at the specific time when this tissue was maximally susceptible to that hormone. It is known that the testicular hormone, testosterone, is intricately involved in embryological development of the male reproductive tract. Testosterone and possibly other steroids are responsible for brain maturational changes (organizing) of the boar sometime during the growth and development phase. During adulthood, testosterone activates the brain to express male sexual behavior. If the boar's brain has not been both organized and activated, adequate male sexual behavior will not be expressed. The objective of this study was to determine whether testosterone or estrogen would activate male sexual behavior in castrated mature male pigs.

Procedure

Seventeen four-way crossbred boars, known to be sexually mature and experienced at mating sows, were castrated at ten months of age. The males were then individually stalled. Ninety days after castration the males were randomly assigned to receive a weekly injection of either testosterone propionate (2 mg/kg of body weight) or estradiol cypionate (100 g/kg of body weight). Sexual behavior was evaluated on two consecutive days at 0, 2, 4, 6, and 8 weeks after initiation of hormone therapy. Sexual behavior traits that were recorded and developed into a libido index score were: time to first mount, time mounted without penis exposed, time mounted with penis exposed, and elapsed time to mating.

Results

Male sexual behavior was initially activated by both testosterone and estrogen. Estrogen injections were not capable of maintaining the same level of response that testosterone produced for mounting behavior (Fig. 1), percent of boars ejaculating (Table 1), and libido index score (Fig. 2).

These results were obtained with postpubertally castrated boars which had previously had their brains "organized" to express male sexual behavior. Thus, we concluded that testosterone activates and maintains those neural processes that are responsible for sexual behavior in boars. In contrast, estrogen was ineffective after the second week of treatment. In future experiments, testosterone replacement therapy will be used to determine the period of time during growth and development when the central nervous system is being "organized" for subsequent expression of male sexual behavior.

[1]Levis is a reproductive physiologist, University of Nebraska-Lincoln, stationed at South Central Research and Extension Center, Clay Center, Nebraska; Ford is a research physiologist, Reproduction Unit, MARC.

Table 1.—Hormonal influence on percentage of boars ejaculating

Week evaluated	Hormonal treatment	
	EC	TP
0	0	0
2	69	78
4[a]	19	83
6[b]	12	67
8[a]	12	83

[a]x^2; EC vs TP are different (P < .01).
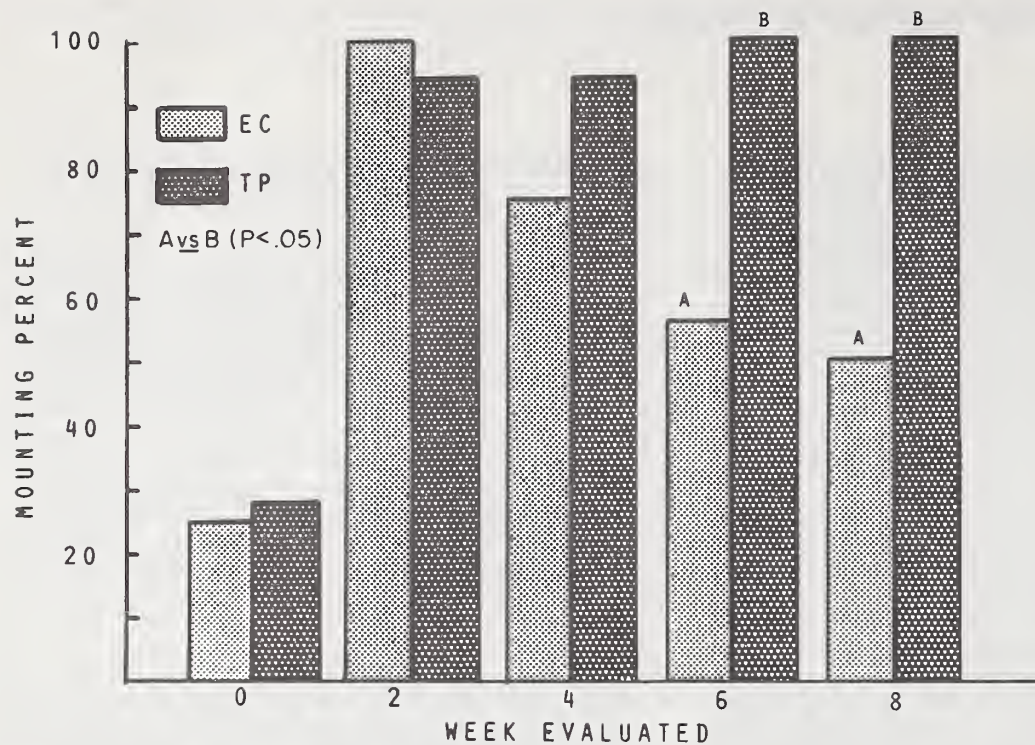[b]x^2; EC vs TP are different (P < .05).

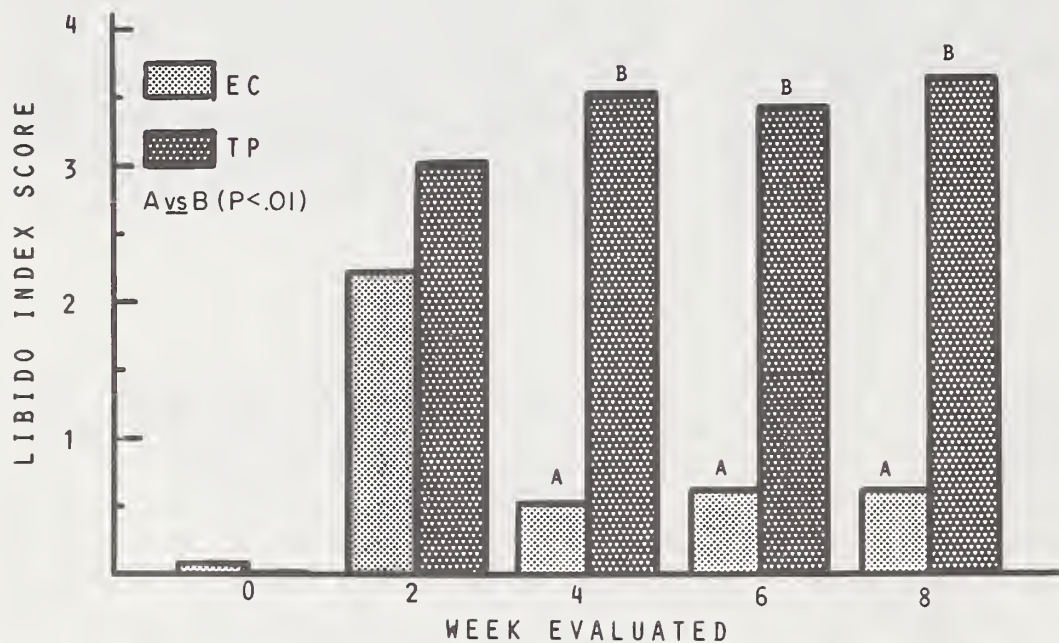**Figure 1**—Hormonal influence on percentage of tests in which mounting was observed.

Figure 2—Hormonal influence on libido index score.

Ovarian Function in the Prepubertal Gilt

Dale A. Redmer, Ronald K. Christenson, and Joe Ford[1]

Introduction

Sow productivity is the outcome of growth of ovarian follicles and their subsequent release of eggs that, after fertilization, develop into litters of pigs. The ovaries also produce sex hormones which are responsible for estrous behavior and maintenance of pregnancy. Therefore, ovarian function must be optimum to achieve puberty and regular estrous cycles, to establish and maintain pregnancy, as well as to ensure postweaning fertility.

The initial stages of follicular growth are important as this is the time when the number of follicles that grow is apparently determined. Unfortunately, the mechanism(s) by which the number of follicles are selected to grow or how the process of follicular growth is controlled are not well understood. There are two hormones from the anterior pituitary gland at the base of the brain, follicle-stimulating hormone (FSH) and luteinizing hormone (LH), which are important in regulating follicular growth in the gilt. In addition there are several hormones and/or factors of ovarian origin which also influence the development and growth of follicles. These hormones and/or factors are found usually in high concentrations in the fluid that fills the follicles. Not all hormones or factors found in follicular fluid have been identified or fully characterized.

After removal of one ovary (unilateral ovariectomy) in either a pre- or post-pubertal gilt, the size and function of the remaining ovary doubles to make up for the missing one. As a result, development or growth of follicles can be stimulated in the prepubertal gilt by removing one ovary. However, the mechanisms involved in compensatory ovarian growth are not understood. The compensatory response to unilateral ovariectomy in the prepubertal gilt provides an experimental model to study the initiation and regulation of ovarian follicular growth and development.

In the following studies, ovarian follicular growth was characterized after unilateral ovariectomy of prepubertal gilts by studying associated hormonal change from both the brain and the ovary. In addition, the effect of follicular fluid on the compensatory response to unilateral ovariectomy was studied to gain further insight into the role of hormones or factors from the follicle on follicular growth and development. The results of these studies are needed in order to develop methods for advancing puberty and reducing the postweaning interval to estrus.

Procedure

Experiment 1. Two groups of prepubertal gilts (130 days of age) were subjected to surgery. Gilts from one group had one ovary removed (ULO), whereas ovaries from the other group of gilts were left intact (controls). On either day 2, 4, or 8 after the initial surgery, a second surgery was performed on all gilts; a blood sample was taken from each ovarian vein, and the ovaries were removed and weighed. Ovarian venous blood was analyzed for the ovarian hormones estradiol and inhibin.

Experiment 2. This experiment was designed to quantitate serum FSH and LH concentrations following removal

[1]Redmer is an assistant professor of animal science, North Dakota State University, Fargo (formerly a predoctoral affiliate, Reproduction Unit, MARC); Christenson is the research leader and Ford is a research physiologist, Reproduction Unit, MARC.

of one ovary. Prepubertal gilts were subjected to either sham (control), unilateral (ULO), or bilateral (BLO) ovariectomy. Blood samples were taken before surgery (0 h) and continued for 48 h after surgery.

Experiment 3. Prepubertal gilts were assigned to one of three treatments: 1) whole porcine follicular fluid (WpFF), 2) charcoal-stripped porcine follicular fluid (CpFF), and 3) charcoal-stripped prepubertal pig serum (PS) as a control. All gilts received 10 ml of their first treatment via jugular injection approximately 18 h before ULO and the second treatment through an indwelling jugular cannula immediately after cannulation and before ULO. Then treatment continued twice daily for 8 days via cannula. At ULO, right or left ovaries were removed, and 8 days later the remaining ovaries were removed. All ovaries were weighed to determine ovarian compensation.

Results

Experiment 1. After ULO, the remaining ovary was heavier on days 4 and 8 with the largest difference on day 8. This ovarian compensation was a result of increased follicular growth and an increased fluid volume within follicles. Concentrations of estradiol and inhibin activity in ovarian venous serum from the remaining ovary was greater for ULO gilts than from either ovary in control gilts on days 2 and 4 (Fig. 1). Concentrations of estradiol and inhibin activity in ovarian venous serum from the remaining ovary in ULO gilts decreased by day 8 to levels similar to that of control gilts. Estradiol concentrations and inhibin activity in ovarian venous serum of control gilts remained low on days 2, 4, and 8, and significant differences between right and left ovarian venous serum were not detected. These research data suggest that ovarian hormones/factors (i.e., estradiol and inhibin) are intricately involved in follicle growth and, upon unilateral ovarian removal, the neuroendocrine system must reprogram through a process of ovarian compensation.

Experiment 2. Serum concentrations of FSH and LH for the first 48 h after control, ULO, or BLO are illustrated in Figures 2 and 3. ULO gilts released more FSH, but not more LH, during the first 24 h after surgery than control gilts. Release of FSH in ULO gilts was intermediate to control and BLO gilts. No differences were found in FSH and LH responses from 24 to 48 h after surgery for ULO and control gilts. These data from prepubertal gilts suggest that upon removal of one ovary, an immediate signal (of ovarian origin) is sent to the brain and/or pituitary which results in an increased release of FSH. Increased serum FSH concentration may be involved in the stimulation of ovarian compensation and increased estradiol concentration and inhibin activity on days 2 and 4. In contrast to the situation in ULO gilts, removal of both ovaries (BLO) causes a dramatic increase in both FSH and LH because the ovarian hormones which normally suppress the secretion of these two pituitary hormones are absent.

Experiment 3. Wet ovarian and follicular fluid weights 8 days after ULO were greater for PS- than for WpFF- and CpFF-treated gilts (Table 1). Ovarian weights obtained at ULO (day 0) and 8 days after ULO showed that ovarian growth of the remaining ovary was evident at 8 days in PS-treated gilts. However, increases in ovarian weights were inhibited by pFF treatment; ovarian weights 8 days after

ULO were similar to ovarian weights before ULO.

These data show that the 130-day-old prepubertal gilt has feedback mechanisms which respond to unilateral ovariectomy. An early response to unilateral ovariectomy is a rise of FSH and increased follicular growth coincident with increased concentrations of ovarian venous estradiol and inhibin. When ovarian follicular fluid weight has nearly doubled, ovarian venous estradiol and inhibin concen-trations are not different from those in control gilts. Follicular fluid treatment after unilateral ovariectomy will prevent the compensatory response after unilateral ovariectomy. It is suggested from these studies that ovarian hormones/factors, including inhibin and estradiol, play an important role in the systemic and local control of follicular growth in the female pig.

Table 1.—Ovarian and follicular fluid weights in porcine serum- and follicular fluid-treated gilts before and 8 days after ULO[a]

| | Treatment[a] | | |
	PS	WpFF	CpFF
Wet ovarian weight (g)			
Day 0[b]	2.6	1.9	2.4
Day 8[c]	4.4[d]	2.0	2.6
Follicular fluid weight (g)			
Day 0[b]	1.3	1.2	1.3
Day 8[c]	2.6[d]	1.0	1.5

[a]Eight gilts/treatment group.

[b]Weights for ovary removed at ULO.

[c]Weights for ovary removed 8 days after ULO.

[d]Porcine serum (PS) treatment mean differs significantly from whole (WpFF) and charcoal-stripped (CpFF) porcine follicular fluid treatment means.
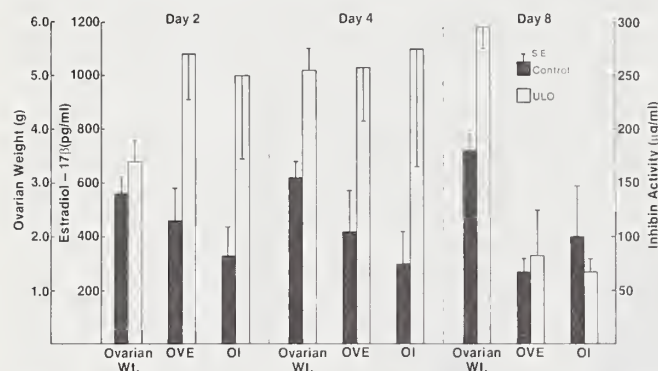

Figure 1—Interrelationships of changes in ovarian weight, ovarian venous estradiol (OVE), and ovarian venous inhibin (OI) levels after unilateral ovariectomy.
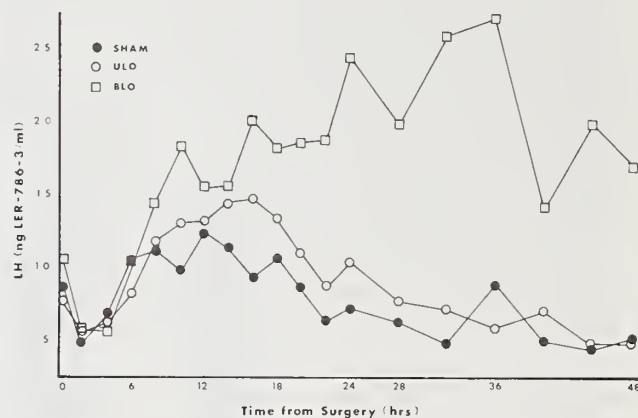

Figure 3—LH concentrations following sham (control), unilateral (ULO), or bilateral (BLO) ovariectomy.
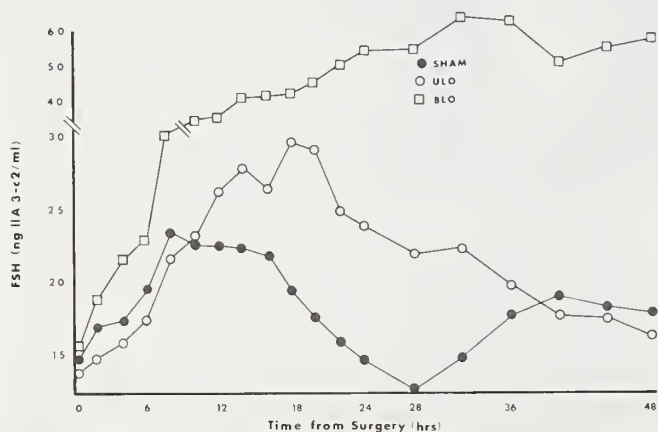

Figure 2—FSH concentrations following sham (control), unilateral (ULO), or bilateral (BLO) ovariectomy.

Serum Proteins and Baby Pig Survival

Roger T. Stone and Kreg A. Leymaster[1]

Introduction

Numerous studies have concluded that the smaller pigs in a litter grow slower and are less likely to survive when compared to the heavier pigs in a litter. Unfortunately, little is known about how the smaller pig differs physiologically or biochemically from its larger littermates. The fact that a given pig weighs less than its genetically similar littermates provides no information as to why it is smaller or what factors are associated with growth retardation. In previous studies, we have shown that the concentration of one of the major serum proteins, serum albumin, is positively correlated with both fetal weight and birth weight. Further, we have suggested that serum albumin concentration might provide a biochemical marker for variations in neonatal growth and survival. Circumstantial evidence supported this idea: Feral swine placed on the Ossabaw Island off the coast of Georgia in the last century and lines of conventional swine selected for backfat thickness have about a 90 percent neonatal survival rate, which is 10 to 20 percent higher than that usually observed in commercial swine operations. Remarkably, baby pigs from these two diverse populations are very similar in their differences in blood parameters and body composition when compared to conventional breeds of swine. Of particular interest to us was the fact that serum albumin concentration at birth in these pigs was two to three times higher than in conventional breeds. We have experimentally tested the idea of albumin concentration being an indicator of baby pig survival in conventional breeds and compared it to birth weight as the commonly used predictor of survival. A useful indicator of baby pig survival could provide a basis for selecting for increased survival.

[1]Stone is a research physiologist and Leymaster is a research geneticist, Genetics and Breeding Research Unit, MARC.

Procedure

Farrowing was synchronized in crossbred sows, and pre-nursing blood samples were collected on pigs from 29 litters. Birth weight and serum albumin concentrations were analyzed in relation to survival to weaning (28 days) and daily gains from 0 to 14 days and from 14 to 28 days.

Results

Survival to weaning was 90 percent in this study, which is higher than we normally average in our herd. At least a part of the higher survival rate can be attributed to attended farrowings. The relationships of pre-nursing serum albumin concentration and birth weight to survival were similar (Fig. 1). Statistical analysis indicated that albumin concentration accounted for 33 percent of the variation in survival compared to 39 percent for birth weight. Combining albumin concentration and birth weight in the statistical model accounted for 57 percent of the variation in survival, which is surprisingly high considering the complexity of a trait such as survival. Compared to birth weight, albumin concentration was not strongly associated with daily gains.

It is probable that serum albumin concentration and birth weight are both indicative of physiological maturity at birth and, thus, survival. The results obtained in this study do not give any indication that albumin would be any better than birth weight has been in selecting for increased baby pig survival. However, these results do leave open the possibility that biochemical markers could be informative in defining physiological maturity at birth. The common practice of selecting the largest, fastest growing pig from a litter for breeding stock, with little or no consideration of littermates, leaves open the possibility that we are maintaining the genetic basis (if there is one) for variations in physiological maturity and survival at birth. Selection for weight may not improve survival and could even be detrimental. This question is not easily approached without a better understanding of physiological and biochemical basis for variation in maturity, growth, and survival.
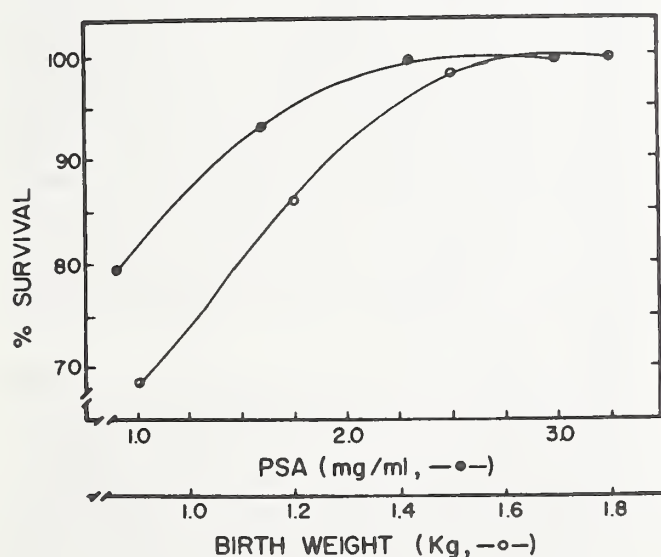

Figure 1—Relationships of survival with pre-nursing concentrations of serum albumin (PSA) and birth weight. The relationships illustrated between dependent and independent traits incorporate effects of covariation with other traits in the multiple regression model.

Puberty and Testicular Development in the Boar

Donald D. Lunstra and Rodney D. Allrich[1]

Introduction

It is a common practice in swine production programs to breed females to boars via natural mating and to select and use boars as herd sires at a relatively young age. The ability to identify and understand the stage of pubertal development within young breeding boars would be of great economic benefit to the producer. There is limited research in the boar and considerable evidence in other species (mouse, bull, ram) that larger testicular size in young males is favorably correlated with improved sperm output, age at puberty, mature testicular size, and pregnancy rate achieved during natural mating. Recent studies on the testes of boars during pubertal development indicate that significant differences in testicular size exist among breeds and considerable variation in testicular size exists within different breeds of boars.[2] The factors that control the onset and degree of testicular development in young boars and the way in which these factors cause the variation observed within and among breeds of boars are largely unknown.

Investigation and characterization of the structural and functional changes that occur within the boar testes during pubertal development are needed in order to establish an understanding of the mechanisms that are responsible for testicular growth and function. The availability of this information would not only allow the producer to select young breeding boars more effectively but would also have significant economic impact on the management of potential herd sires from birth through breeding age.

The present study is part of a larger program of research designed to characterize relationships between the anatomical, hormonal, and functional changes that occur during testicular development in the boar. The objectives of the present study were to (1) characterize the structural (histological) changes that occur in the boar testes before, during, and after puberty; and (2) investigate the functional and ultrastructural changes that occur in the testicular cells (Leydig cells) that produce steroid hormones, including testosterone (T) and estradiol (E2), during pubertal development of the boar testes.

Procedure

Forty-eight Landrace X Duroc boars born within a 3-week period during the spring and weaned at 4 weeks of age were used in this study. The boars were randomly assigned at weaning to eight castration ages (40, 70, 100, 130, 160, 190, 220, and 250 days of age). The boars were reared under standard management conditions in a total-confinement environment (nursery until 70 days of age, finishing pens with 16 boars/pen until 150 days of age, and then individual stalls until 250 days of age). Corn-soybean meal diets containing 18, 16, and 14 percent protein were fed *ad libitum* to boars in nursery, finishing pens, and stalls, respectively, except that feed was limited to 6 lb daily in stalls.

Five days before the scheduled castration date for each group of boars, sterile medical tubing was placed in the external jugular vein, and blood samples were taken every 30 min between 8 a.m. and 12 noon two days before castration. At castration, anesthesia was induced and maintained via intravenous injection of sodium thiopental. Testes and epididymides were removed, trimmed of excess tissue, and weighed. Small tissue samples (0.5 g) were quickly taken from the right testis, minced, and placed in incubation flasks containing buffered media. A hormone (human Chorionic Gonadotropin, hCG), which acts like luteinizing hormone (LH) and stimulates testicular tissue to produce and release T and E2, was added (0-3,125 mIU) to the incubation flasks. Subsamples of the media were removed from each flask during a 3-h *in vitro* incubation. Blood serum samples and samples of incubation media were stored frozen (-4°F) until the quantities of T and E2 present were determined by radioimmunoassay.

As the right testis was being processed for incubation, the left testis was perfused via the testicular artery with a buffered fixative (3 pct gluteraldehyde and 1 pct formaldehyde) to preserve the tissue structure. Small pieces of fixed tissue were removed, embedded, sectioned, and stained for evaluation using both light microscopy and electron microscopy. These microscopic evaluations allowed the morphology and ultrastructure of the developing boar testes and Leydig cells to be defined at each age, and relationships to testicular function (hormone production and onset of sperm production) were investigated.

Results

Paired testes weight increased continuously between 40 and 250 days of age (Fig. 1). Testes weight increased slowly between 40 and 100 days of age, but increased very rapidly beyond 100 days of age, particularly between 100 and 190 days of age. Based on histological evaluation of testicular tissue, the increase in testes weight was accompanied by an increasing mass of total Leydig cells (the steroid hormone producing cells of the testes) and seminiferous tubules (the structures in which spermatozoa are produced). The total weight of Leydig cells in the testes closely paralleled the increase in paired testes weight in boars between 40 and 100 days of age (Fig. 1). Total weight of Leydig cells continued to increase between 100 and 160 days of age, but at a less rapid rate than that occurring in paired testes weight. Total weight of Leydig cells per paired testes plateaued at 160 to 190 days, decreased slightly between 190 and 220 days of age, and stabilized at approximately 60 to 65 grams between 220 and 250 days of age.

It is interesting to note that fully developed spermatozoa were first observed in a few seminiferous tubules at 100 days of age and the testes of all boars were producing spermatozoa at 130 days of age. This initiation of sperm production (puberty) coincided with the time frame (100 to 130 days of age) in which the rate of increase in paired testes weight began to diverge from the increase in total weight of Leydig cells (Fig. 1). The divergence between paired testes weight and total weight of Leydig cells in boars beyond 100 days of age is explained by the rapid increase in mass of seminiferous tubules that occurred during development of the boar testes. The percentage of the

testes occupied by seminiferous tubules increased dramatically between 70 and 190 days of age (Fig. 2), and this increase was particularly rapid between 100 and 130 days of age and coincided with the onset of spermatogenesis (puberty).

The percentage of the testes occupied by Leydig cells decreased continuously in boars between 70 and 220 days of age (Fig. 2), and appeared to stabilize at approximately 10 percent between 220 and 250 days of age. However, the total number of Leydig cells per paired testes increased steadily and rapidly from 40 days to 160 days of age and increased little beyond 160 days of age (Fig. 2). Collectively, these data indicated that the individual Leydig cell must undergo significant changes in cell size (volume) during testicular development in the boar.

Evaluation of the size and structure of Leydig cells by light and electron microscopy confirmed that dramatic changes in Leydig cell volume and ultrastructure occur in the boar testes before, during, and after puberty. Volume of the individual Leydig cell declined between 40 and 100 days, increased rapidly to a peak at 130 to 160 days, and then declined to intermediate levels by 220 to 250 days of age (Fig. 3). The pattern of change in the intracellular volume occupied by cell organelles per Leydig cell was highly correlated with the changes in Leydig cell volume (r = .40 to .99; P < .01), and this was particularly true for volume of smooth endoplasmic reticulum (SER; r = .97) and total volume of mitochondria (r = .88) per boar Leydig cell (Fig. 3).

The steriod-producing capacity and gonadotropin (hCG) sensitivity of the boar Leydig cell was obtained by incubation of testicular tissue and the results were compared to the data on Leydig cell structure, volume, organelles, and number. Production of T and E_2, expressed per boar Leydig cell, also peaked at 130 to 160 days (Fig. 3), and was highly correlated to average Leydig cell volume, volume of SER, and number and total volume of mitochondria per Leydig cell (r = .63 to .84; P < .01). The peak in steroid producing capacity per Leydig cell at 130 to 160 days coincided with a marked increase in number of gonadotropin receptors (LH - hCG) per Leydig cell (Fig. 3). The reduced steroid-producing capacity per Leydig cell that occurred in boars at 190 to 250 days of age (Fig. 3) indicated that production of T and E_2 is more closely linked to Leydig cell structure (volume and organelles) than it is to number of gonadotropin receptors per Leydig cell in the post-pubertal boar, since Leydig cell volume and organelles were reduced in boars beyond 190 days of age but number of gonadotropin receptors remained high (Fig. 3).

The peak in steroid producing capacity and the maximums in Leydig cell, SER, and total mitochondrial volume and number of gonadotropin receptors per Leydig cell all occurred at 130 to 160 days of age, an age that corresponds well with the onset of spermatogenesis (puberty) and is simultaneous with dramatic rates of increase observed in paired testes weight, total weight of Leydig cells per paired testes, and the percentage of the testes occupied by seminiferous tubules. The reason for the decline in Leydig cell size, intracellular organelles, and sensitivity to gonadotropin stimulation that occurs postpubertally requires further investigation. Additional studies to evaluate the effects of breed, nutrition, season, and other factors on testicular development and Leydig cell structure and function in the boar before, during, and after puberty are needed.
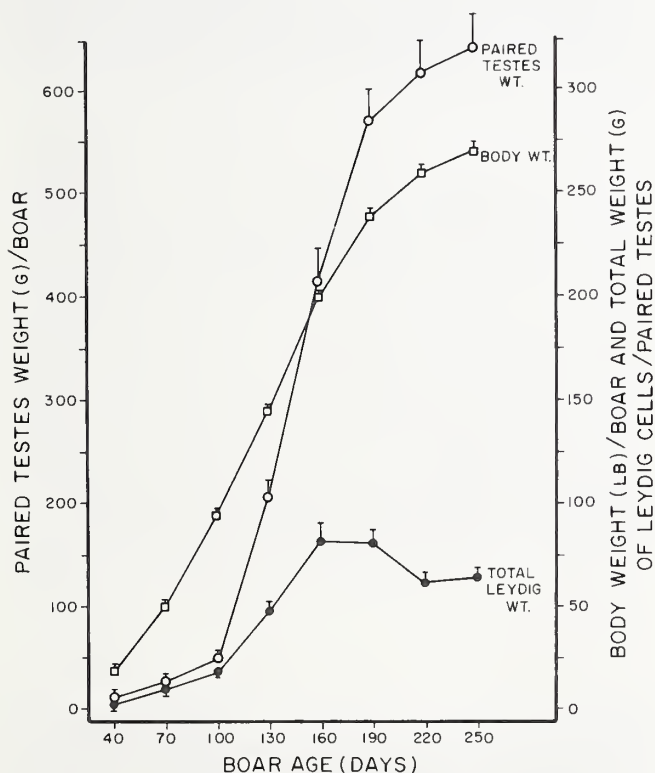
Figure 1—Paired testes weight (grams), total weight (grams) of Leydig cells/paired testes, and average body weight (lb) of boars between 40 and 250 days of age. Values are mean ± SE per boar.
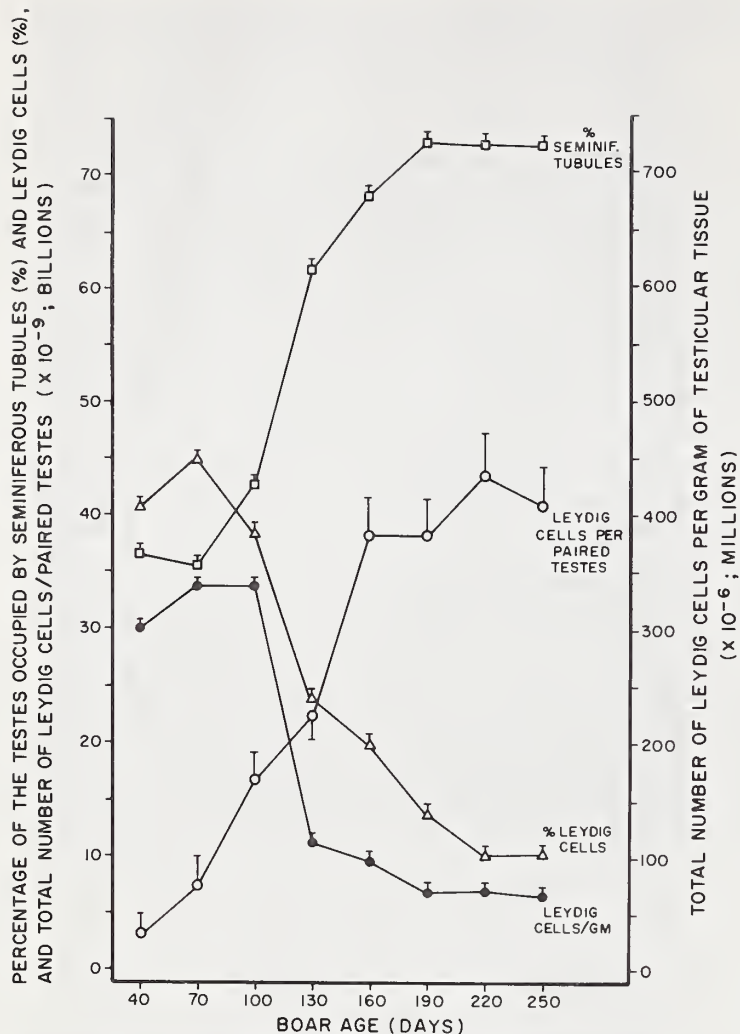
Figure 2—Percentage of the testes occupied by seminiferous tubules and Leydig cells, and total number of Leydig cells per paired testes (billions = 10⁻⁹) and per gram of testicular tissue (millions = 10⁻⁶) in boars between 40 and 250 days of age. Values are mean ± SE per boar.
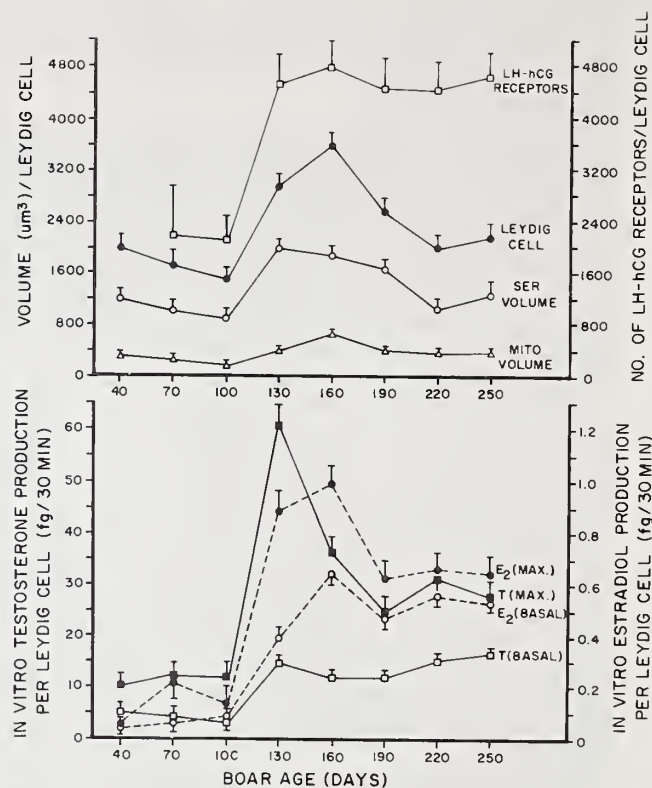
Figure 3—Comparison of the steroid-producing capacity per Leydig cell (lower panel) and structural characteristics per Leydig cell (upper panel) in boars between 40 and 250 days of age. Basal (0 mIU hCG/ml incubation media) and maximal (3125 mIU hCG/ml incubation media) production rate for testosterone (T) and estradiol (E₂) were derived from *in vitro* incubations. Values are given as mean ± SE per Leydig cell.

Mapping of the Gene for G Blood Group Antigens to Chromosome Number 15 in Swine

Ralph R. Maurer and Hans R. Fries[1]

Introduction

With the increased interest in genetic engineering, mapping of genes on chromosomes has become of more interest in the domestic mammals. Basically, gene maps contain information about linkage (i.e., whether two or more gene loci are on the same chromosome within a genetically measurable distance of each other and stay together in inheritance) and the location of genes on chromosomes. Two methods are available to obtain the information about the linkage of two gene loci and chromosomal location. The first method is family studies which can provide evidence that two given gene loci are on the same chromosome within a genetically measurable distance from each other. A modification of using the two gene loci procedure would be to use a marker on a chromosome and a gene loci on the same chromosome. The second method is to use clones of hybrid cells derived from interspecies somatic cell hybridization to demonstrate that two particular gene loci are carried by the same chromosome.

Chromosomes are made up of a pair of spindle fibers called chromatids. The point at which the two chromatids are attached to each other is called the centromere. The centromere contains one or more stainable granules which stain differently than the material in the chromatid. The point where the two chromatids are joined differs for each chromosome. Some chromatids are joined in the middle (metacentric) while others are jointed near one end (acrocentric) or at the end (telocentric). The staining properties of the centromere for individual chromosomes has been shown to be inherited by Mendelian inheritance. Chromosomes are identified by their staining properties, i.e., each chromosome has a characteristic staining (banding) pattern to quinacrine mustard dihydrochloride or other suitable stains.

Blood groups are identified by the reaction to specific antiserum for each blood group. If the specific blood group antigen is present, it will cause a blood clotting reaction. If the blood group antigen is absent, no clotting will occur.

From previous studies by Dr. Fries and colleagues, some evidence indicated that the G blood group locus may be located on chromosome 15. Studying metaphase chromosomes from a group of boars for another study, it was noted that some boars had large differences in size of the centromeric region on homologous chromosome 15. Therefore, the opportunity to study the segregation of centromeric variants (size of the staining properties) of chromosome 15 and G blood group alleles in the offspring of these boars and females, whose chromosomes and blood types were identified, could provide the evidence needed to assign the G blood group locus to chromosome 15.

Procedure

Six boars were selected for segregation studies based on the large differences in sizes of the centromeric regions of their homologous chromosomes 15. These six boars were mated to 26 sows. Thirteen of the twenty-six matings were informative, i.e., one parent was dihybrid (heterozygous regarding the centromeric region of chromosome number 15 and the G blood group locus). The male was the dihybrid parent in all except one mating. The mating types were eight double-backcross matings (one parent dihybrid and the other parent doubly homozygous) and five single-backcross matings (one parent dihybrid and the other monohybrid). The boars and sows were crossbreds with an equal genetic contribution from Chester White, Landrace, Large White, and Yorkshire breeds.

Blood samples were collected from the boars and sows for cytogenetic examination (chromosome analysis) and for blood typing. Blood samples for cytogenetic examination and blood typing were collected from the piglets at 3 to 8 weeks of age. Red blood cells were washed twice by centrifugation in physiological saline solution and tested for the G blood factor by the blood cell clumping test. Precise details of the blood group and chromosome analysis were described in the literature.

Chromosomes were prepared from peripheral blood lymphocytes incubated for 72 h at 101°F in medium containing Ham's F-10 medium, fetal calf serum, pokeweed mitogen, heparin, and antibiotics. Colcemid was added one h before lymphocyte harvest to arrest cell division at the metaphase stage in the lymphocytes. Hypotonic treatment and histological fixation was completed before the chromosomes were stained with quinacrine mustard dihydrochloride. The quinacrine mustard staining allowed the chromosome to be Q-banded which enables the chromosomes to be individually identified by the banding patterns of light and dark regions. The quinacrine mustard has fluorescence properties, and, therefore, the chromosomes were observed and photographed with a Zeiss Photomicroscope III equipped with a Xenon light source and filter combination. The chromosome slide preparations were also stained with barium hydroxide for C-banding, which stains the centromeric region of the chromosome (Figure 1). The centromeric region of chromosome 15 was scored by size in C-banded chromosomes. Each chromosome metaphase spread was photographed and chromosome 15 was identified from Q-banding. The centromeric region of the C-banded chromosome 15 was scored from 1 (very small centromere region) to 5 (very large centromere region). Four to six metaphase spreads were analyzed per animal.

The statistical examination of the segregation data for the linkage of size of centromere region of chromosome 15 and the G blood group locus followed the lod score method (a mathematical method to assess the association of chromosome 15 and the G blood group locus). Lod scores were calculated for each dihybrid parent separately. Lod scores greater than 3 were significant for linkage while a lod score smaller than -2 two was significant for rejection of the linkage hypothesis.

[1]Maurer is a research physiologist, Reproduction Unit, MARC; and Fries is currently on the staff of the Institut for Tierproduktion, Federal Institute of Technology Zurich, Zurich, Switzerland (formerly a postdoctoral fellow, Reproduction Unit, MARC).

Results

The table showing individual G blood group typing and scoring of the centromeric region of chromosome 15 as well as statistical data can be found in Animal Blood Groups and Biochemical Genetics 15:251-258 (1984). The segregation of the centromeric variants of chromosome 15 was studied in 107 offspring of the 13 matings, while blood type data were obtained in 103 of the offspring. There were four different male dihybrid parents and one female dihybrid parent. The Chi-square analyses of the segregation data indicated that the G blood group alleles and the centromeric variants of chromosome 15 did not deviate significantly from the expected 1:1 ratio. The Chi-square analyses of the segregation ratios of the haplotypes (centromere size on one chromosome 15 and blood type for one G loci) showed a significant deviation from the 1:1 ratio in four of the five dihybrid parents. This deviation would be expected in the case of linkage of two alleles. The calculation of the lod scores, which was based on frequencies of the different haplotypes, indicated four of the five dihybrid parents had positive lod scores. The overall score (5.03) was greater than 3 indicating significance for accepting the hypothesis that centromeric variants on chromosome 15 and the G blood grooup locus are linked. A test of the lod scores for similarity indicated that all five lod scores should be included in the total score. Therefore, the hypothesis of the G blood group locus and centromeric region of chromosome 15 being linked can be accepted. This study provided further evidence that G blood group antigens are encoded by genes located on chromosome 15. Since this was the second investigation to show linkage between a number 15 marker chromosome and the G blood group locus, the assignment of the G blood group locus to chromosome 15 is confirmed.

Even though the test of the five lod scores indicated similarity among scores, considerable variation of the recombination frequencies among different dihybrid parents was observed. This indicated that there may have been differences in crossing-over frequency or in the location of the G blood group locus on chromosome 15 derived from different breeds. All the dihybrid animals were crossbreds with equal contribution of Large White, Landrace, Chester White, and Yorkshire breeds.
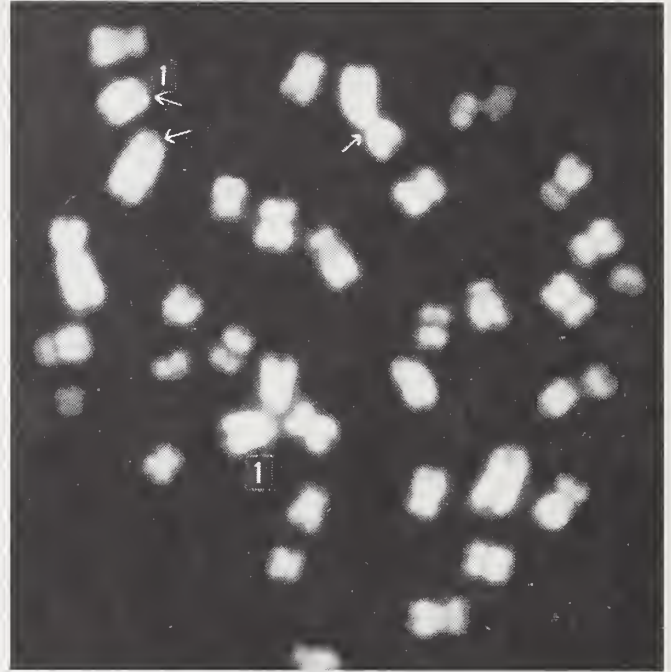

Figure 1—Swine chromosome metaphase spread. The one's indicate the pair of chromosome 15. The arrows point to a centromere region.

Developmental Changes in Secretion of Growth Regulating Hormones in Pigs

John Klindt[1]

As pigs develop, many changes occur. Embryonically, some organ systems develop prior to others. After birth, the pattern of growth changes as the pig develops. The growth of the young pig is characterized by muscle growth with a relatively small amount of fat deposition. As the pig matures, the proportion of the growth that is muscle decreases and the proportion that is fat increases. This differential partitioning, or directing, of nutrients to muscle and fat with development represents more and more production of fat with minimal value. Understanding the regulation of this differential nutrient partitioning may allow the control of partitioning of nutrients and thus have the more mature pig grow like a young pig (i.e., more muscle growth than fat deposition).

The endocrine system, or the hormones, coordinate the systems of the animal. A hormone is a substance produced by one organ which is released into the blood and has a regulatory action on another organ of the body. Two hormones which appear to be important in the regulation of growth are growth hormone and prolactin. Both of these hormones are produced by the pituitary gland. These hormones are regulated by release stimulating and release inhibiting hormones or factors from the hypothalamus, a region of the brain. Both of these hormones are secreted in an episodic manner. Periodically, there is a burst of secretion followed by a period of a low or basal secretion. This episodic pattern of secretion does not appear to fit a predictable rhythmic pattern. Evidence from laboratory animals and sheep indicate that the pattern of secretion of these hormones does have physiological importance. The secretory patterns can be defined in terms of overall mean, the average of the concentration of the hormone in all the samples collected during the sampling period; the baseline mean, the basal or threshold concentration; and the number and amplitude or height of the secretory peaks. In our work, we have found that it is essential to collect samples every 15 min for 8 h in order to adequately define the secretory patterns.

Figure 1 presents the weight of and circulating growth hormone and prolactin concentrations in fetal pigs during the last two-thirds of gestation. During this period, the weight of the fetal pigs increases almost 100-fold, from 10 g to 1000 g. The circulating concentration of growth hormone in the fetus is low (2-3 ng/ml) at 40 days of gestation and increases in a manner roughly parallel to the changes in fetal weight until approximately 80 days of gestation. After that point, the concentrations change little. The circulating prolactin concentrations are characterized by an elevation in concentration between 50 and 60 days of gestation and from 80 days of gestation to term. The relevance of these peaks of fetal prolactin secretion is not presently understood.

In the growing male pig the patterns of secretion of growth hormone and prolactin change with development (Figs. 2 and 3). From 5 weeks to 24 weeks of age, the overall mean concentration of growth hormone declines. This decline occurs without changes in baseline concentration or frequency of secretory peaks. The apparent source of the age associated decline in overall mean concentration of growth hormone is diminished height or amplitude of

the secretory peaks. This reduced amplitude of growth hormone peaks may represent a reduction in hypothalamic secretion of the growth hormone releasing factor, increased secretion of the growth hormone release inhibiting factor, or a reduced ability of the pituitary to respond to the growth hormone releasing factor.
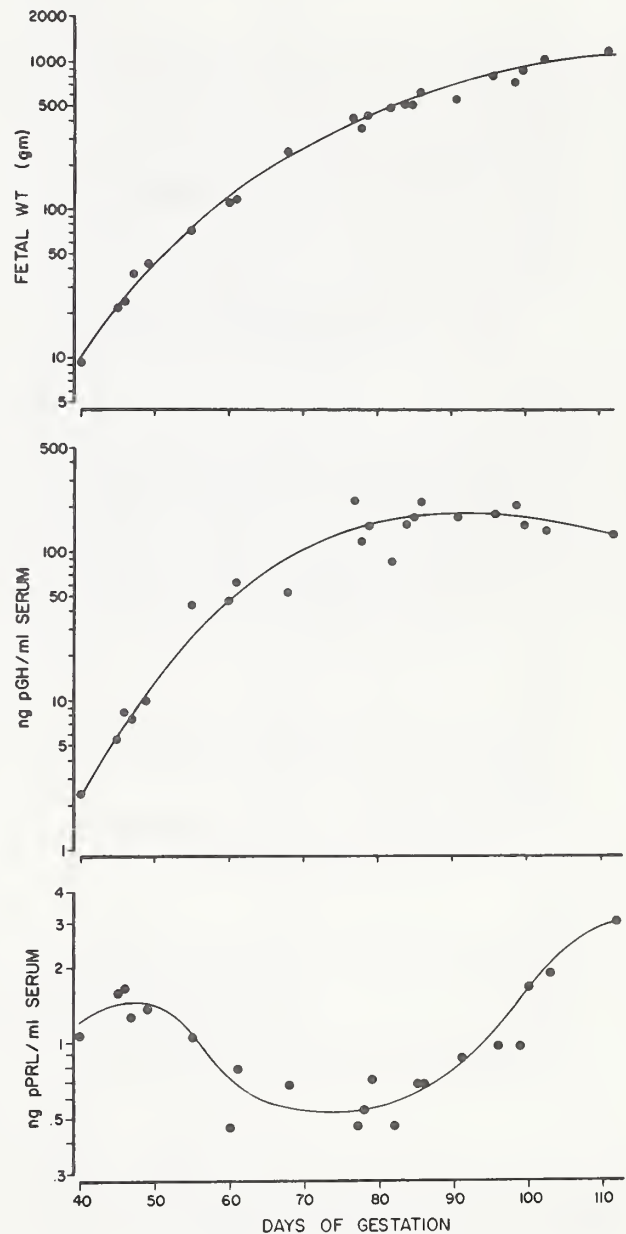
Figure 1—Fetal weight, GH concentrations, and PRL concentrations from 40 to 112 days of fetal age. Each point represents the mean of the litter means at that age.

[1]Klindt is a research physiologist, Meats Unit, MARC.

Changes occur in the secretory patterns of prolactin as well. As with growth hormone, the overall mean concentration of prolactin declines with age and/or development. This decline in overall concentration of prolactin is primarily due to a reduction in both the frequency and amplitude of prolactin secretory peaks. These data suggest that the age-associated decline in prolactin is the result of a decreased ability or propensity of the hypothalamus or higher brain centers to initiate bursts of prolactin secretion.

The young growing male pig is characterized by high growth hormone secretory peaks and high and more frequent prolactin secretory peaks. It may be that maintenance of these patterns of secretion into the later periods of development would maintain the pattern of growth which is characteristic of the young pig (i.e., primarily muscle growth with relatively little fat deposition).

Figure 3—Temporal concentrations of PRL in four individual animals of each sampling age group. The animal number is presented in the upper left of each panel.

Figure 2—Temporal concentrations of GH in four individual animals of each sampling age group. The animal number is presented in the upper left of each panel.

Effect of Sex on Swine Adipose Tissue Metabolism

Harry J. Mersmann[1,2]

Introduction

Numerous observations on growing swine indicate differences in growth rate, feed conversion, and body composition between sexes. Intact males tend to grow faster, convert feed to body weight more efficiently, and to be less obese than castrated males; whereas, females tend to grow slower than either male type, but are more efficient and less obese than castrated males. In some studies, the rate of gain may not differ among the sexes. However, the higher dietary protein requirement for males may complicate the results because males are not fed greater dietary protein than females or castrated males in most growth trials.

The purpose of this study was to assess the rate of adipose tissue synthesis of fat in male, female, and castrated male pigs. Demonstration of differences in rates of fat synthesis might explain some of the gross differences observed in body composition between the sexes.

Procedure

Pigs were male or female Yorkshire x Landrace reciprocal crossbreds. They were raised in environmentally controlled buildings under normal husbandry conditions and weaned at 4 weeks of age. One group of males was left intact and three others castrated at birth, 2, and 4 months of age, respectively. There were eight animals in each group.

Adipose tissue biopsies were obtained from the dorsal neck region at 20 weeks of age. Tissue slices ($<$ .5 mm) were prepared and [^{14}C(U)] D-glucose incorporation into CO_2 and into a total lipid extract were measured by using 100 mg of slices/flask. After incubation at 98.6°F for 120 min, the liberated CO_2 was collected, and the medium plus tissue was extracted with chloroform and methanol to yield a total lipid extract. The trapped CO_2 was counted in a liquid scintillation counter, as was 50 percent of the lipid extr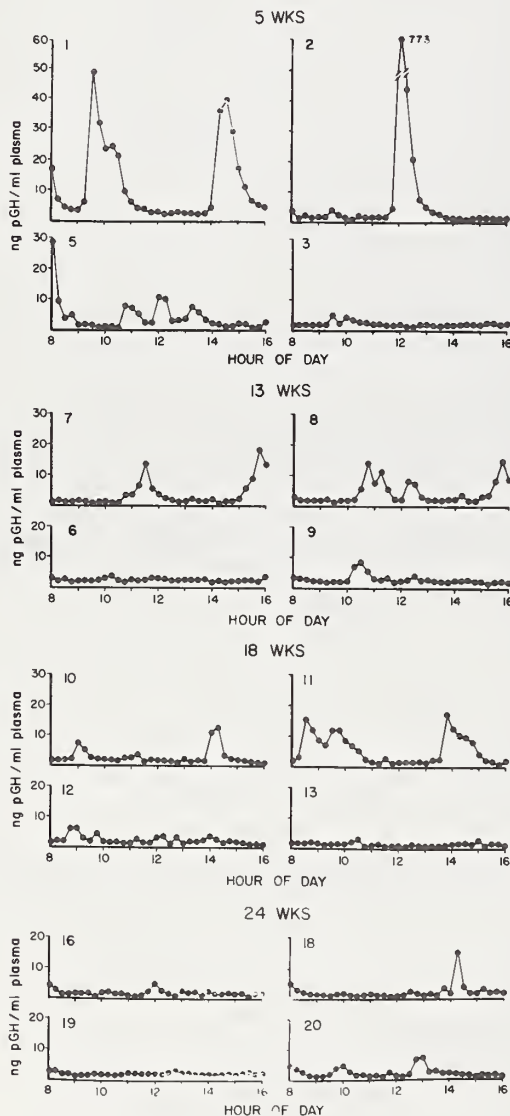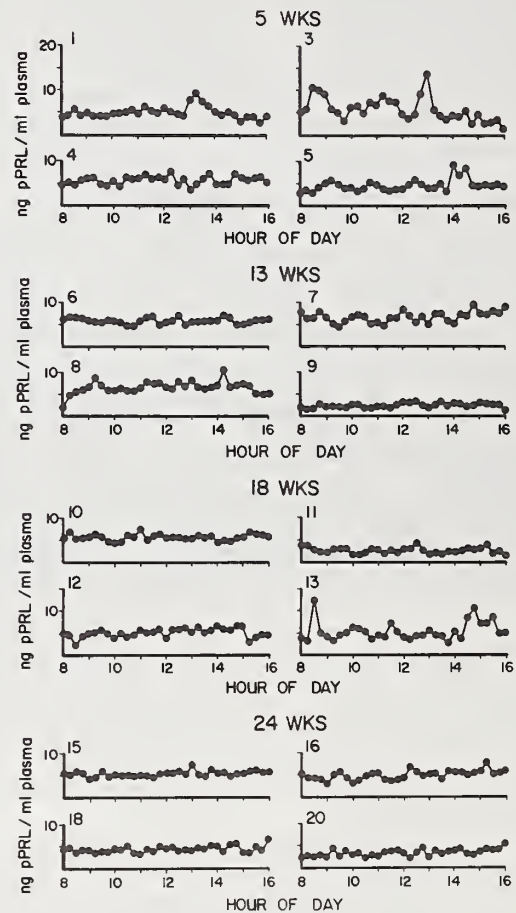act. The other one-half of the lipid extract was saponified and separated into nonsaponifiable, glyceride-fatty acid, and glyceride-glycerol fractions. Each fraction was counted in a scintillation counter.

Backfat was probed ultrasonically at 20 weeks of age at the first and last ribs and the last lumbar vertebra about 5 cm lateral to the middorsal line. Adipose cell size was determined with a particle counter. Metabolic data was expressed on a cell number basis.

Results

Pig weights were the same ($P > .05$) in all sex groups (Table 1). Intact males were leaner at 20 weeks of age (as evidenced by backfat thickness) than females or males castrated at birth or at 2 months of age. Males castrated at 4 months tended to have intermediate fatness. Adipocyte cell size was less in intact males than males castrated at birth or at 2 months. Females and males castrated at 4 months tended to have intermediate cell size. Glucose metabolism to CO_2 or total lipids was less in male and tended ($P > .05$) to be less in female pigs than in any group of castrated male pigs.

The present studies in swine demonstrated the expected trends in fatness as indicated by backfat thickness (males $<$ females $<$ castrates) and in accompanying adipocyte cell size even though body weights among the groups were similar. The decreased amount of fat in males was accompanied by a lower capacity for fat synthesis (glucose incorporated in lipids) at 20 weeks of age. Greater divergence in fat synthesis capacity of adipose tissue among sexes might be observed by assessment of other ages, stages of the reproductive cycle, or adipose tissue from different anatomical sites. However, the mechanism for divergent rates of fat synthesis in the sexes is not yet clear.

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[1]Mersmann is a research chemist, Meats Unit, MARC.

[2]Details of this work are found in the Journal of Animal Science 58:600, 1984.

Table 1.—Sex effects on weight, backfat, adipocyte cell size and fat metabolism in swine

Variable	Sex					
	Female	Male	Day 0 castrate	2 Mo castrate	4 Mo castrate	SE
Weight, lb	170.3	150.9	166.5	166.8	153.3	8.4
Backfat, mm	19^{yx}	14^x	21^z	21^z	17^{xy}	2
Cell volume, μm^3 x 10^{-5}	3.1^x	2.8^x	4.8^y	5.0^y	2.6^x	.5
Glucose oxidation[a]	.84^{xy}	.64^x	1.17^{yz}	1.32^z	1.24^{yz}	.15
Glucose incorporation into fat[a]	1.34^{xy}	1.02^x	1.99^{yz}	2.10^z	2.05^z	.24

[a]μmol [^{14}C-U] glucose incorporated into CO_2 or total lipid fraction X 120 min^{-1} X 10^6 cells^{-1}.

[xyz]Values on the same line with different superscripts differ ($P < .05$).

Hormonal Control of Degradation in Fat

Harry J. Mersmann[1]

Introduction

The increase in mass of a tissue in growing animals is the end result of the rate of synthesis of the tissue coupled with the rate of degradation of the tissue. If the biological control of synthesis and degradation could be understood, then ways to manipulate the growth of a specific tissue could be devised. In adipose tissue, or fat, the metabolic pathways for synthesis are modestly well understood. Furthermore, at least some of the ways in which the rate at which these pathways function in various dietary or hormonal states have been measured. Much less is known about the degradative metabolic pathways in adipose tissue. The purpose of this work is to establish the effectiveness of several metabolic hormones to regulate the degradative processes.

Procedure

Adipose tissue was obtained from anesthetized pigs by biopsy procedures. Tissue slices were prepared and incubated to measure the rate of lipid degradation in the absence or presence of various hormones. Fatty acids were measured in the incubation medium as the product of degradation of the storage lipid, triglyceride.

Pigs were anesthetized and a carotid artery cannula was inserted to sample the blood and to measure heart rate and blood pressure. Hormones were infused into an ear vein. Blood samples were analyzed for content of free fatty acids as the product of adipose tissue degradation. Free fatty acid in the blood can be modified by dietary intake and by the rate of utilization by various tissues as an energy source.

Results

In rat adipose tissue, most hormones that affect metabolism in general also stimulate (or, in the case of insulin, inhibit) adipose tissue degradation processes. The rat may not, in this case, be a good laboratory organism in which to study hormonal control because its adipose tissue is responsive to many hormones that adipose tissue from other species is not. Porcine adipose tissue responds to very few of the spectrum of metabolic hormones. The adrenal medullary hormone, adrenaline, stimulates lipid degradation in porcine adipose tissue slices (Table 1) about three- to six-fold (varies with the pigs). The synthetic hormone isoproterenol, similar in structure to adrenaline, also is very effective. The pituitary gland hormones, growth hormone and adrenocorticotropin, yield very slight or no stimulation of degradation (Table 1). Each of these hormones can be made active by the addition of theophylline to the incubation medium for porcine adipose tissue slices. Theophylline presumably inhibits the degradation of the intracellular second messenger, cyclic AMP, and thus allows the expression of the hormone effect. Several other hormones, the pancreatic hormone glucagon, the pituitary gland hormone thyrotropin, and the thyroid gland hormone thyroxine, do not stimulate lipid degradation. Furthermore, at least for glucagon, there also was no stimulation in the presence of theophylline.

At least as far as they have been tested, these results obtained with tissue slices are confirmed in the intact pig when hormone is infused into a vein and plasma free fatty acid concentration is measured as an indicator of lipid degradation. Adrenaline and isoproterenol both stimulate; growth hormone does not stimulate; and glucagon does not stimulate degradation (Table 1). The exception so far is that adrenocorticotropin that was essentially inactive in the tissue slice (unless theophylline was added) produced a substantial increase in blood levels of free fatty acid.

The pancreatic hormone insulin has a primary role in regulating carbohydrate metabolism by stimulating sugar transport into the cell. Insulin also stimulates lipid synthesis in adipose tissue. Insulin also decreases lipid degradation in adipose tissue. When porcine adipose tissue slices are incubated with varying concentrations of insulin, the isoproterenol stimulated lipid degradation rate can be inhibited 90 percent. The concentration of insulin to achieve this inhibition of lipid degradation was about 200 μ Units per ml. When insulin was infused into a pig along with isoproterenol to stimulate adipose tissue degradation, the degradation was inhibited about 25 percent when blood plasma levels of insulin reached about 90 μ Units per ml.

These studies indicate that porcine adipose tissue degradation potentially can be controlled over a short period (hours) by several hormones. Adrenaline may be the most important hormone to yield stimulation of degradation. Other hormones such as glucagon seem to have no role, but the activity of several hormones, such as adrenocorticotropin and possibly thyrotropin, is not yet clear. Insulin can inhibit adipose tissue lipid degradation; its role in the pig may not be a major one, for the amount of inhibition observed (25 pct) with quite high blood insulin levels was not very profound. Certainly, it is obvious that adipose tissue in the pig responds to hormones in a different fashion than the common laboratory animal, the rat. Consequently, studies in the rat may suggest biological control mechanisms in other species but do not define those controls in a particular species.

Table 1.—Degradative response of porcine adipose tissue

Hormone	Relative tissue degradation rate[a]	Relative pig response[b]
Adrenaline	100	100
Isoproterenol	100	100
Growth hormone	< 10	< 10
Growth hormone + theophylline	90	Not tested
Adrenocorticotropin	< 10	50
Adrenocorticotropin + theophylline	80	Not tested
Glucagon	< 10	< 1
Glucagon + theophylline	< 10	Not tested
Thyrotropin	< 20	Not tested
Thyroxine	< 10	Not tested

[a]Relative degradation rates. Isoproterenol was used as a standard hormone and yielded about 25 μ Eq fatty acid release X g tissue[-1] X 120 min^{-1} or a relative rate of 100. Hormone levels were varied by orders of magnitude to determine an approximation of the maximal response, regardless of dose. Responses less than 20 percent that of isoproterenol may or may not be real; however, they cannot be quantified.

[b]Relative release of free fatty acids to the blood stream. Isoproterenol was considered as a standard hormone and yielded an increase in circulating free fatty acid of about 2000 μ Eq X liter[-1].

[1]Mersmann is a research chemist, Meats Unit, MARC.

Fat Metabolism in Obese Pigs

Harry J. Mersmann[1, 2]

Introduction

Duroc and Yorkshire pigs were selected over more than 14 generations for backfat thickness by Hetzer and coworkers (USDA). No other selection criterion was applied. After the selection process, obese pigs had over 60 percent greater backfat thickness than the unselected controls, and lean pigs had over 25 percent less backfat thickness than the unselected controls. The obese and lean progeny of this selection have been maintained at the MARC from matings of Duroc obese x Yorkshire obese and Duroc lean x Yorkshire lean pigs. The obese pigs represent an extreme example of the tendency for pigs to excessively fatten during growth. Consequently, they may provide us with clues to the biological control of fat deposition in pigs. Furthermore, the obese pigs may represent a model for certain types of human obesity.

The metabolic alterations that occur in these pigs have not been extensively studied. We do know that the obesity is not accompanied by large changes in carbohydrate metabolism. Obese pigs are not diabetic, as are many of the rat and mouse models for obesity. Consequently, we have examined the synthesis and degradation of fat in adipose tissue itself (the depot fat) to reveal how these processes are controlled in the obese and lean pigs.

Procedure

Pigs were anesthetized and adipose tissue was obtained from beneath the skin in the dorsal neck region. Tissue slices were prepared and incubated with radioactive glucose to measure the rate of synthesis of fat. (In nonruminant animals, the major dietary carbohydrate used for synthesis of fat is glucose.) At the end of incubation, the lipids were extracted and the radioactivity measured. There were six pigs in each group of obese, lean, and contemporary pigs; they were studied monthly at 3 to 6 months of age.

To study rate of fat degradation, tissue slices were incubated and at the end of the incubation time, the fatty acids (product of fat degradation) that had been released from the tissue were determined. There were 20 obese and 20 lean pigs studied at 55 and 176 lb body weight.

Fifty obese and fifty lean pigs were bled at 2, 4, and 6 months of age. Blood samples were obtained from fed pigs and then again after a 30 h fast. Free fatty acid concentration in the blood plasma was measured.

Results

Obese pigs weighed slightly less than lean pigs at each age studied (Table 1). Because this selection was only for backfat thickness and not growth rate and because the selection was stopped over 15 years ago, neither the obese nor the lean pigs grow as fast as contemporary pigs (Table 1).

Not only was the backfat thickness greater in obese than lean or contemporary pigs, but the size of the fat cells (Table 2) was greater in obese than lean or contemporary pigs at 3 months of age. These differences were maintained to 6 months of age.

The rate of synthesis of fat from glucose was greater in obese than lean or contemporary pigs at all ages from 3 to 6 months (Table 3). It appears that the excessive fat deposition in obese pigs results, at least partially, from the increased ability of obese pigs to synthesize fat.

In the experiment to measure fat degradation (Table 4), the obese pigs had larger fat cell size at both 55 and 176 lb body weight. The fat degradation rate was similar in obese and lean pigs at 55 lb but was greater in obese than lean pigs at 176 lb body weight. When fat degradation was stimulated with a hormone (adrenaline) the rate of fat degradation was greater in obese than lean pigs at both weights (Table 4). The data appear to indicate that the obesity is not caused by a decreased ability to degrade fat. Rather, adipose tissue from obese pigs has slightly greater degradative rates than that from lean pigs.

Another indicator of fat degradation may be the blood plasma concentration of free fatty acids, the product of fat degradation. Concentrations of free fatty acids were measured at 2, 4, and 6 months of age. In fed pigs, the obese animals had equal or slightly greater levels of free fatty acids than lean pigs (Table 5). After a fast during which fat degradation is increased to provide energy to the animal, the obese pigs had less product of fat degradation, free fatty acid, in the blood than did lean pigs (Table 5).

Overall, these approaches to understand metabolism in adipose tissue of obese and lean pigs indicate that the excess deposition is controlled mainly by the rate of synthesis of fat and not by the rate of degradation. If degradation were important, the rates would be expected to be less in obese than lean pigs, but they were equal or even greater in obese than lean pigs (Table 4). The blood levels of free fatty acids, the product of fat degradation, indicate the same type of results in fed pigs (Table 5). However, in the fasted state, the obese pigs have lower levels of free fatty acid. If these blood levels reflect the rate of fat degradation in the intact animal, then the possibility exists that fat degradation has a role in metabolic control of fat deposition.

Table 1.—Pig weights (lb)

Age	Obese	Lean	Contemporary[a]
3 mo	49.1	60.9	60.9
4 mo	93.1	106.9	127.2
5 mo	134.0	150.0	190.3
6 mo	172.0	183.0	221.5

[a]Duroc x Large White.

Table 2.—Adipose tissue cell size[a]

Age	Obese	Lean	Contemporary
3 mo	1.8	1.0	1.1
4 mo	2.6	1.5	2.1
5 mo	2.9	1.6	2.2
6 mo	3.7	1.6	2.4

[a]Volume $= 10^5 \mu m^3$.

Table 3.—Fat synthesis from glucose[a]

Age	Obese	Lean	Contemporary
3 mo	350	219	268
4 mo	497	342	411
5 mo	269	156	223
6 mo	311	112	168

[a]μmol glucose incorporated x g^{-1} x 120 min^{-1}.

Table 4.—Fat degradation

	Obese	Lean	Obese	Lean
Weight, lb	57.2	52.8	176.0	180.4
Fat cell size, $10^5 \mu m^3$	2.40	1.45	4.94	2.64
Degradation rate[a]	1.07	.93	2.29	1.17
Adrenaline stimulated degradation rate[a]	6.22	4.36	9.32	7.95

[a]μmol free fatty acid released x g^{-1} x 120 min^{-1}.

Table 5.—Plasma free fatty acids[a]

	Fed pigs		Fasted pigs	
Age	Obese	Lean	Obese	Lean
2 mo	290	274	1,148	1,317
4 mo	183	179	757	973
6 mo	188	154	659	823

[a]μq per liter.

Blood Plasma Cholesterol and Response of the Cardiovascular System to Diet in Obese and Lean Swine

Wilson G. Pond, Harry J. Mersmann, and Jong-Tseng Yen[1]

Introduction

Obesity, dietary cholesterol, and saturated fat intake are all considered important factors related to the high incidence of cardiovascular disease in humans. The pig has become a widely used model for use in studies of human atherosclerosis. A population of genetically obese and lean pigs (Yorkshire x Duroc pigs derived from matings of obese with obese and lean with lean purebreds selected for 20 generations for high or low backfat thickness) has been shown to have similar plasma cholesterol, triglyceride and glucose levels, and normal glucose tolerance. Such pigs offer a unique tool to ascertain the importance of obesity *per se* as a component of atherosclerosis. Available evidence suggests that moderately overweight humans in the U.S. population may not be more susceptible to atherosclerosis than individuals at the recommended mean body weight. Nutritional requirements of humans reported in the literature seldom address the effect of desirable body weight on the response to dietary treatment.

The purpose of the present experiment was to determine the plasma lipid response and the development of aortic plaques in genetically obese and lean pigs fed a standard diet (low fat-low cholesterol) or a diet containing tallow and egg yolk (high fat-high cholesterol). The results should provide useful information to the swine producer about the need to change pork consumption to meet human preferences and concerns.

Procedure

Thirty-two castrated male Duroc x Yorkshire pigs, representing a lean and an obese population described in the introduction (16 obese and 16 lean), were assigned randomly within genetic groups at about 50 days of age to one of two dietary treatments, a low fat-low cholesterol all plant diet or a similar diet containing 11 percent beef tallow and 1 percent dried egg yolk (Table 1). All pigs were penned separately and fed *ad libitum* for 4 months at which time one-half of each group (8 lean and 8 obese pigs fed each diet) was slaughtered. All other pigs continued on their respective diets and were fed at 4 lb per animal daily for 1 additional year.

Blood was sampled from each pig monthly for 4 months and bimonthly for 12 months for determination of total plasma cholesterol and triglycerides. At slaughter, the aorta from the aortic arch to the bifurcation of the ileac arteries was removed, opened longitudinally, and stained with Sudan IV for identifying lipid deposits. Stained areas were measured, and the affected area was expressed as a percentage of total aorta surface area. Backfat depth (mean of three measurements) and the cross-sectional area of loin eye muscle and fat at the 10-11th rib interface were recorded for each pig.

Results

Body weight, backfat thickness, and cross-sectional area of loin eye muscle and of the associated subcutaneous fat layer are shown in Table 2 for pigs slaughtered at 18 months of age. Body weight of pigs slaughtered at 6 months was unaffected by breed or by diet, but backfat thickness (mean of three measurements over first rib, last rib, and last lumbar vertebra) and subcutaneous fat area at the 10-11th rib interface was greater in obese than lean pigs (as expected) and greater in pigs fed the high fat diet than in those fed the low fat diet. Loin eye muscle cross-sectional area was greater in lean than in obese pigs but was unaffected by diet. The same trends persisted in pigs slaughtered at 18 months as shown in Table 2.

Plasma cholesterol and triglyceride concentrations and percentages of aorta surface area occupied by fat-stainable tissue are shown in Table 3 for pigs slaughtered at 18 months of age. Neither plasma cholesterol nor triglycerides exceeded 200 mg/dl even at 18 months of age, indicating that both obese and lean pigs are relatively refractory to high fat-high cholesterol diets. There appeared to be a rise in plasma cholesterol in pigs of both genetic lines fed either diet from the start of the experiment (2 months of age) to 6 months of age. Obese pigs had significantly lower plasma cholesterol and plasma triglycerides than lean pigs initially, but the reverse was

Table 1.—Composition of diets

Ingredient	Low fat (pct)	High fat (pct)
Corn, No. 2, yellow dent	70.6	53.6
Soybean meal[a]	25.0	30.0
Dicalcium phosphate	2.4	2.4
Ground limestone	0.8	0.8
Iodized salt	0.4	0.4
Vitamin premix[b]	0.2	0.2
Choline chloride[c]	0.2	0.2
Trace mineral premix	0.4	0.4
Beef tallow	-	11.0
Dried egg yolk	-	1.0
	100.0	100.0
Ether extract fat, pct	3	14
Cholesterol, mg/lb[d]	0	167

[a]At 12 months of age one-half of the pigs fed low fat and one-half of the pigs fed high fat diets within each genetic line were fed casein replacing soybean meal as the amino protein source to slaughter at 18 months of age. Crude casein (85 pct protein) was fed at 14 and 16.5 percent of the low fat and high fat diets, respectively, at the complete expense of soybean meal. Corn was increased to 81.6 and 67.1 percent of low fat and high fat diets into which casein was substituted.

[b]Supplies the following (units/kg diet): vitamin A, 5,280 IU; vitamin D_3, 704 IU; vitamin E, 70.4 IU; vitamin K, 3.52 mg; vitamin B_{12}, 26.4μg; riboflavin, 5.28 mg; niacin, 28.16 mg; D-pantothenic acid, 21.12 mg; biotin, 88μg; thiamine, 2.2 mg.

[c]Supplies the following (ppm): Cu (as cupric oxide), 10; Fe (as ferrous sulfate heptahydrate), 160; Mn (as manganese oxide), 20; Zn (as zinc oxide), 100; $CaCO_3$ used as carrier (0.30 pct of diet).

[d]Tallow contains 95 mg and dried egg yolk 2,630 mg of cholesterol per 100 g.

[1]Pond is research leader and Yen is a research animal scientist, Nutrition Unit; Mersmann is a research chemist, Meats Unit, MARC.

true at 6 months. The high fat-high cholesterol diet produced significantly greater plasma cholesterol concentrations in both lean and obese pigs than did the low fat-low cholesterol diet at 6 months. Despite these moderate rises in plasma cholesterol associated with high dietary fat-cholesterol, there were no aortic lipid deposits at 6 months as assessed by Sudan IV staining.

Concentration of plasma cholesterol from 6 months to 12 months of age tended to be less in both genetic lines and in both diet groups than that observed at 6 months of age, presumably due to the restricted feed intake imposed after 6 months. Obese pigs had higher cholesterol and higher triglycerides than lean pigs and dietary fat-cholesterol supplementation significantly increased both constituents in both genetic lines at 12 months. Lean pigs showed a greater plasma cholesterol response than did obese pigs to dietary fat-cholesterol supplementation.

Pigs slaughtered at 18 months of age differed in plasma cholesterol from 12 to 18 months between genetic lines (obese to lean) and between dietary fat-cholesterol levels (high fat to low fat).

Plasma triglycerides were higher in obese than in lean pigs from 12 to 18 months of age, and a trend toward opposite response of lean pigs to dietary fat-cholesterol supplementation resulted in a genetic line x diet interaction.

All pigs slaughtered at 18 months of age, regardless of genetic line or of diet, showed some Sudan IV stainable aortic involvement. The mean percentage of the total aorta surface area affected tended to be greater for lean pigs than for obese pigs (14.1 pct vs 8.4 pct) and greater for pigs fed high fat-high cholesterol than for those fed low fat-low cholesterol diets (13.5 pct vs 9.0 pct).

The results of this experiment with genetically obese and lean castrated male pigs fed diets containing no animal fat or cholesterol or 11 percent beef tallow and 1 percent dried egg yolk (167 mg cholesterol/lb diet) indicate that genetically controlled obesity per se is not necessarily associated with increased plasma cholesterol or triglycerides or with a greater tendency, compared with genetically lean pigs, toward increased plasma cholesterol or triglycerides when dietary fat and cholesterol are increased. The failure of obese and lean pigs in this experiment to develop hyperlipidemia when fed a high fat-high cholesterol diet is in contrast to other reports in which pigs were of different genetic backgrounds and fed diets higher in cholesterol than in the present experiment. There is evidence of genetic difference in resistance to atherogenesis in response to diet in swine. The failure of a diet containing 11 percent tallow-1 percent dried egg yolk to increase plasma cholesterol in the present experiment to levels generally associated with a high incidence of heart disease in humans is in accord with the relative freedom from lipid accumulation in the aortic surface as assessed by Sudan IV fat stain. Others have observed a high correlation between serum cholesterol concentration and aortic cholesterol content in pigs with aortic lesions following consumption of a high fat-high cholesterol diet. Therefore, the association between serum cholesterol and ischemic heart disease in humans appears to exist also in swine susceptible to atherosclerosis. The serum lipoprotein profile of swine resembles that of humans more closely than other species except nonhuman primates.

It is expected that the knowledge gained from this type of research with swine will provide important information to the swine producer for providing pork to meet more adequately what the consumer wants in composition and healthfulness.

Table 2.—Backfat thickness and cross-sectional area of loin eye and backfat, at 10-11th rib interface of genetically lean or obese pigs fed diets with or without tallow-egg yolk supplementation (least-squares means)

Trait	Genetic line (G): Diet(D):	Obese		Lean		Proba- bility
		Low fat	High fat	Low fat	High fat	
		18 months old				
Number of pigs		4	4	4	4	
Slaughter weight, lb		401	360	393	384	D <0.01
Backfat, in		3.4	3.3	1.4	1.8	G <0.01
Loin eye lean area, sq in		3.44	3.92	6.43	5.95	G <0.01
Loin eye fat area, sq in		12.05	12.03	6.90	7.38	G <0.01

Table 3.—Plasma cholesterol and triglycerides and percentage of aorta stainable with Sudan IV of genetically lean or obese pigs fed for 16 months diets with or without tallow-egg yolk supplementation (least-squares means)

Trait	Genetic line (G): Diet(D):	Obese Low fat	Obese High fat	Lean Low fat	Lean High fat	Probability
		6 months to 12 months old[a]				
Number of pigs		4	4	4	4	
Plasma cholesterol, mg/dl		88	116	73	112	G, D, C x D 0.01
Plasma triglycerides, mg/dl		61	72	38	68	G 0.05; D 0.01
		12 months to 18 months old[b]				
Number of pigs		4	4	4	4	
Plasma cholesterol, mg/dl		120	128	87	123	G, D 0.01; G x D 0.10
Plasma triglycerides, mg/dl		45	42	23	30	G 0.01; G x D 0.07
Sudan IV stained aorta, pct of area		7.4	9.3	10.5	17.7	NS

[a]Before casein replaced soybean meal in the diet of one-half of the pigs.

[b]After casein replaced soybean meal in the diet of one-half of the pigs. Since there was no significant effect of protein source on any trait measured, data from dietary protein groups were combined.

Growth and Composition of Progeny from Feed-Restricted Dams

Wilson G. Pond, Harry J. Mersmann, and Jong-Tseng Yen[1]

Introduction

The effects of the amount of prenatal food intake on subsequent growth and development of the offspring are important, yet inadequate information is available.

Restriction of energy intake during gestation to one-half the recommended allowance for swine reduces the birth weight of individual piglets without apparent permanent effects on postweaning growth. However, starvation for 40 days in middle or late gestation reduces piglet birth weight and neonatal growth. The effect of energy restriction to less than one-half the recommended allowance during more than one-half of gestation has not, to our knowledge, been reported in swine.

This experiment was designed to test and quantify the responses to severe maternal feed restriction in swine.

Procedure

Twenty-seven crossbred (Chester White x Landrace x Large White x Yorkshire) sows were mated after weaning their first litters, and assigned sequentially on the day of breeding to one of three treatment groups: A, adequate feed (4 lb/day) throughout pregnancy; ER, early restricted (1.3 lb/ day) intake during the first 70 days, then adequate to term; LR, late restricted (1.3 lb/day) intake during the last 70 to 75 days of pregnancy. A standard corn-soybean meal diet was fed to each group during gestation. Only data from sows that produced a litter were used (7, 6, and 9 sows in groups A, ER, and LR, respectively). Sows were kept in individual feeding stalls in a well-ventilated building from day 1 through day 110 of gestation and fed their allotted feed once daily. At day 110, they were moved to slatted-floor individual stalls in a central farrowing building, where they remained through a 4-week lactation period. From day 110 of gestation to parturition at 112 to 114 days, all sows were fed 4 lb of feed daily. Beginning on the day of parturition, all sows were offered a standard lactation diet *ad libitum*.

Body weight of each sow was recorded at breeding, through week 16 of pregnancy, day 2 postpartum, and at the end of a 4-week lactation period. Backfat thickness at three points (shoulder, midback, and rump), each 3 cm lateral to the dorsal midline, was estimated by ultrasonic probe of each sow at 10 and 14 weeks of gestation, day 2 postpartum, and after 4 weeks of lactation. The number of pigs born alive and stillborn and individual pig birth weights were recorded for each litter. Sow and piglet feed consumption to weaning were measured for each litter; number of pigs weaned and individual pig weaning weights were recorded. At weaning, three male and three female piglets were selected randomly from each litter to be fed (as a group) an 18 percent protein ration *ad libitum* to 70 days of age. At 70 days, two males and two females were retained (in pairs by sex within a litter) to 25 weeks of age. The diet from 70 to 112 days of age was formulated to contain 16 percent protein. From 112 to 175 days, this diet was diluted with 10 percent tallow to increase caloric density. The diet met National Research Council recommended nutrient requirements even after dilution. Individual pig weights and feed consumed by each pen of 6 pigs, to 70

days of age, or each pair of pigs, from 70 to 175 days of age, were recorded biweekly.

Pigs were slaughtered at 25 weeks of age. The chilled carcass weight, carcass length, cross-sectional areas of the longissimus muscle, and the subcutaneous fat at the 10-11th rib interface, weights of untrimmed and trimmed (skin and fat removed to about 0.64 cm fat depth) ham, loin, Boston butt, and picnic, percentage of trimmed lean cuts in the carcass (trimmed ham + loin + Boston butt + picnic divided by cold carcass weight), and weight of perirenal (leaf) fat were recorded for each pig. A sample of subcutaneous fat (overlying and last rib, 2 in lateral to vertebral column) and of perirenal fat was removed from each pig at slaughter for estimating fat cell size and number.

Results

Body weight and backfat thickness of sows changed as would be predicted from digestible energy intake. ER sows tended to lose weight during the first 10-week period and then gained weight from 10 weeks to parturition at a rate not significantly different from that of A sows. Similarly, LR sows gained weight at a rate similar to that of A sows during the first 6 weeks of pregnancy and then maintained weight during the remainder of pregnancy when food intake was severely restricted.

Backfat thickness reflected gestation energy intake patterns for LR and A sows. By 10 weeks of restricted feeding, ER sows had backfat only one-half as thick as that of LR and A sows; at week 16, even though feed intake had been increased, the extra energy was not reflected in increased backfat thickness. In LR sows, less severe reduction in backfat thickness was noted after 10 weeks of diet restriction, but backfat (week 16 of gestation) was less in both ER and LR sows than in A sows. Backfat of ER gilts remained unchanged between 16 weeks of pregnancy and 4 weeks of lactation while that of LR and A sows increased.

Litter size and number of stillbirths were not significantly affected by maternal feed intake during gestation, but mean litter birth weight and individual pig birth weight were less in pigs from ER and LR sows than in pigs from A sows (Table 1). Mean piglet weaning weight was similar in all three groups. Sow feed consumption during lactation was not significantly affected by pregnancy diet regimen. However, ER sows tended to consume more feed than other groups, presumably in response to less mobilizable depot fat present to meet lactation demands.

Mean body weight gain during the first 6 weeks after weaning (4 to 10 wk of age) was less in progeny of LR sows than in those of other sows (33.2, 27.3, and 34.1 lb for progeny of A, LR, and ER dams, respectively). From 10 to 25 weeks of age progeny of ER and LR dams had significantly lower body weights than those from A dams. Results of gain to feed ratio and carcass measurements are summarized in Table 2. Feed consumption was decreased proportionately more than weight gain in ER progeny, resulting in a tendency for a greater gain to feed ratio in ER progeny than in progeny of other sows. Carcass weight was similar for all groups. Pigs from ER dams tended to be leaner than pigs from other dams, as indicated by greater trimmed ham and loin weights (untrimmed weights were similar; therefore, there was less fat trim), less perirenal (leaf) fat, and a tendency for a lower cross-

[1]Pond is the research leader, Yen is a research animal scientist, Nutrition Unit; Mersmann is a research chemist, Meats Research Unit, MARC.

sectional area of fat at the 10-11th rib interface.

Mean fat cell diameter was smaller in progeny of ER dams than of LR or A dams; mean fat cell volume tended to be less in progeny of ER dams, but the difference did not reach statistical significance. Males had fat cells with a larger volume than those of females, but mean cell diameter and total number of perirenal fat cells were unaffected by sex.

This experiment extended earlier work which addressed the effects of energy restriction during pregnancy on postnatal progeny development. The results of that work indicated no permanent effect on the progeny by mater-

nal energy restriction to one-half of the recommended allowance throughout pregnancy. The present experiment provided evidence that severe maternal feed restriction (2,000 kcal DE daily, one-third of recommended allowance) early or late in pregnancy does have important effects on postnatal growth and development of the progeny in swine. Further work will be done to develop life cycle feeding strategies that may result in a saving in feed required for breeding females while, at the same time, improving carcass leanness and efficiency of feed utilization of their progeny.

Table 1.—Effect of maternal feed restriction during early or late gestation on litter size, birth weight, and weaning weight of swine progeny[a]

| Trait | Diet for dam | | | Probability |
	ER	LR	A	
No. of litters	6	9	7	
No. of pigs/litter	8.3	8.9	10.7	NS
No. of stillborn/litter	0.3	1.2	0.3	NS
No. born alive/litter	8.0	7.7	9.7	NS
Litter wt at birth, lb	23.3	21.2	31.6	ER,LR <A(P <.05)
Mean birth wt, lb	2.78	2.42	3.17	ER,LR <A(P <.01)
No. weaned/litter	6.7	6.0	8.6	NS
Litter wt at weaning, lb	90.4	92.8	127.6	ER,LR <A(P <.01)
Mean weaning wt, lb	14.6	16.3	15.2	NS
Lactation feed intake, lb	327	265	294	NS

[a]Values are means. ER, dams restricted in early pregnancy (first 10 wk); LR, dams restricted in late pregnancy (last 10 wk); A, dams fed adequately; NS, not significant.

Table 2.—Effect of maternal feed restriction during early or late gestation on gain/feed and carcass measurements of swine progeny

| Trait | Sex | | Diet for dam[a] | | | Probability[b] |
	Male	Female	ER	LR	A	
No. of pigs	37	37	20	24	30	
Gain/feed[c]	0.188	0.177	0.185	0.183	0.178	NS
Cold carcass wt, lb	176	184	180	181	179	Sex, P<.01
Carcass length, in	33.0	32.7	32.7	32.8	33.0	NS
Ham wt, lb						
Untrimmed	20.2	21.5	21.3	20.8	20.6	ER vs A,P< .05
Trimmed	17.1	17.1	17.7	17.0	16.7	ER vs A,P< .01
Loin wt, lb						
Untrimmed	22.1	23.5	22.6	23.0	22.8	Sex, P <.01
Trimmed	16.5	16.7	16.8	16.7	16.3	ER vs A,P <.05
Picnic wt, lb						
Untrimmed	10.3	9.8	10.2	10.0	9.9	Sex, P<.05
Trimmed	9.5	8.2	8.5	8.5	9.6	NS
Loin eye fat, sq in	7.2	8.0	7.0	7.8	8.0	ER vs A,P <.07
Perirenal fat, lb	3.48	4.18	3.56	3.94	3.97	ER vs A,P <.01
Lean cuts, pct	59.4	54.6	57.27	55.78	57.91	NS

[a]ER, dams restricted in early pregnancy (first 10 wk); LR, dams restricted in late pregnancy (last 10 wk); A, dams fed adequately; NS, not significant.
[b]By least-square means.
[c]Data are from 10 weeks of age to slaughter at 25 weeks of age.

Effect of Alfalfa Meal on Growth, Reproduction, and Nutrient Digestibility in Swine

Wilson G. Pond, Jong-Tseng Yen, and Vincent H. Varel[1]

Introduction

Previous research has shown the feasibility of utilizing alfalfa as an energy source for growing-finishing and gestating swine. Reduced growth and decreased feed utilization are often encountered when alfalfa meal constitutes more than 20 percent of the diet. One possible reason for this effect is that protein requirements may be increased in the presence of high fiber. On the other hand, if fiber level does not increase protein requirement, the contribution of alfalfa to satisfying part of the protein requirement would provide an attractive alternative when the cost of traditional protein supplements is high. The ability of the sow to utilize high levels of alfalfa for reproduction is well established. The usefulness of dehydrated alfalfa meal as the sole energy and protein source for pregnant sows depends on the intake of adequate calories when the diet is full-fed. The use of corn cobs as a means of providing part of the energy requirement for reproduction offers a potential opportunity for utilizing this by-product of corn production. We report here the results of experiments with growing-finishing and pregnant swine fed dehydrated alfalfa meal as a major diet component.

Growing-finishing swine. Eighty crossbred barrows and gilts were fed diets containing 0, 20, or 40 percent alfalfa meal in which the alfalfa meal replaced corn only or corn and soybean meal in proportion to the amounts present in the basal diet (16 pigs fed each of five diets). Daily weight gain and feed consumption were measured and standard carcass measurements were recorded for each pig at slaughter.

Gestating gilts. Thirty-two crossbred first-litter gilts (eight gilts fed each of four diets) were used to determine the effect of dietary fiber source and level fed throughout gestation on reproductive performance and apparent digestibility of diet constituents. The diets included a standard corn-soybean meal gestation diet (4 lb daily), similar diets containing 20 percent corn cobs or 40 percent dehydrated alfalfa meal, or a diet containing 96.4 percent alfalfa meal plus vitamin and mineral supplements. The 96.4 percent alfalfa meal diet was not well accepted, so the amount of that diet fed daily was 3 lb throughout gestation. During weeks 7 to 9 of gestation, 4 randomly selected gilts per treatment were used to determine apparent digestibility of diet constituents.

Results

Growing-finishing swine. The results are summarized in Table 1. The presence of alfalfa meal in the diet had no effect on gross energy intake. Daily weight gain was reduced significantly by 20 percent and still further by 40 percent alfalfa meal. Both levels of added alfalfa meal reduced backfat thickness of both barrows and gilts. Carcass length and cross-sectional area of the loin eye muscle at the 10-11th rib interface were unaffected by diet but were greater in gilts than in barrows. Growth and carcass traits were affected by alfalfa meal to a similar degree when it replaced corn only, or when it replaced corn and soybean meal. This suggests that alfalfa meal is a satisfactory source of protein and that it can replace at least part of the soybean meal in a corn-soybean meal diet for growing-finishing swine.

Gestating gilts. The results are summarized in Table 2. Total and live pigs per litter were not affected by maternal diet. Newborn live pigs from dams fed 96 percent alfalfa meal were significantly smaller than other pigs. The smaller size at birth persisted to weaning at 4 weeks of age, although the average total litter weight was not significantly different among treatments at weaning. Daily weight gain from 28 to 63 days of age was not significantly affected by the dam's gestation diet, but when the entire period from 0 to 63 days was considered, pigs from dams fed 96 percent alfalfa meal had a significantly lower daily gain than pigs from dams fed all other diets during gestation. Number of pigs weaned per litter was not affected by diet.

Digestibility of crude protein was unaffected by diet, but apparent digestibility of gross energy, dry matter, and ether extract was lower in dams fed 96 percent alfalfa meal than in dams fed other diets.

[1]Pond is the research leader, Yen is a research animal scientist, and Varel is a research microbiologist, Nutrition Unit, MARC.

Table 1.—Weight gain, feed consumption, and carcass measurements of growing-finishing pigs fed diets differing in alfalfa meal, corn, and soybean meal levels (least-squares means)

Diet no.: Diet designation: Trait	1 Basal	2 20 pct alfalfa replacing corn and SBM	3 40 pct alfalfa replacing corn and SBM	4 20 pct alfalfa replacing corn	5 40 pct alfalfa replacing corn	Sex[a]	
						Gilt	Barrow
No. of pigs	16	16	16	16	16		
Daily gain, lb[b]	1.87	1.60	1.48	1.63	1.44	1.55	1.65
Gain/feed	0.338	0.275	0.265	0.245	0.255	0.266	0.271
Slaughter wt, lb[b]	216	209	198	204	196	211	198
Backfat, in[c]	1.23	1.07	1.04	1.11	1.02	1.00	1.19
Length, in	30.5	31.0	31.1	31.0	30.9	31.4	30.4
Loin eye area, sq in	4.61	4.67	4.51	4.72	4.82	5.04	4.32

[a]Different (P <.01) for all traits except daily feed and gain/feed, no sex x diet interactions.

[b]Basal greater than other groups (P <.01) and 20 percent alfalfa meal greater than 40 percent alfalfa meal (P <.01).

[c]Basal greater than all other groups (P <.01).

General conclusion

The use of up to 40 percent dehydrated alfalfa meal in the diet of growing-finishing pigs and up to 96 percent in the diet of pregnant gilts appears to be an acceptable feeding practice. Digestible energy of the diet is reduced by such a practice, resulting in leaner carcasses and slower weight gain in growing-finishing pigs and in reduced individual pig birth weight in gestating gilts. The rather low palatability of diets containing high levels of dehydrated alfalfa meal may be related to such components as saponins, phenolics, organic acids, and plant pigments, or to an effect of the high temperature of the dehydration process on diet acceptability.

Table 2.—Effect of gestation diet fiber level and source on sow weight, lactation, feed consumption, reproductive performance, progeny weight gain, and diet digestibility for dams

| | Trial: | Diet | | | |
Item		Control[a]	96 pct dam	20 pct corn cobs	40 pct dam
No. of gilts		8	8	8	8
Total pigs/litter		8.4	9.1	9.0	10.4
Live pigs/litter		8.1	9.0	8.9	9.2
Vigor score[b]		2.5[c]	1.9[d]	2.5[c]	2.4[c]
Birth wt, all pigs, lb		2.96[c]	2.37[d]	2.84[c]	2.72[c]
Birth wt, live pigs, lb		2.96[c]	2.38[d]	2.85[c]	2.86[c]
Litter wt, all pigs, lb		25.1	21.6	25.3	28.8
Litter wt, live pigs, lb		24.2	21.3	25.1	26.0
Feed in lactation, lb		264[c]	288[d]	287[d]	278[d]
Creep feed/litter, lb		10.8	11.9	14.3	12.5
Prepartum wt gain, lb		112[c]	7[d]	98[c]	96[c]
Pigs weaned/litter		7.6	8.4	8.0	8.6
Pig wt at weaning (4 wk), lb		14.5[c]	11.4[d]	14.3[c]	14.1[c]
Litter wt at weaning, lb		108	94	110	118
Daily gain 28-63 day, lb		.57	.48	.55	.50
Daily gain 0-63 day, lb		.50[b]	.41[c]	.48[b]	.44[bc]
Digestibility coefficients (pct)					
Dry Matter					
Gross energy		83.1[c]	60.3[d]	76.6[c]	76.1[c]
Crude protein		79.1	71.2	81.3	76.9
Ether extract		69.1[c]	43.1[d]	79.0[c]	69.4[c]
Digestible energy, kcal/lb		1,615	1,169	1,483	1,503

[a]The control diet contained corn, soybean meal, 1 percent alfalfa meal, and vitamin-mineral supplements. Other diets contained indicated supplements substituted for corn and soybean meal.

[b]Three = strong, 2 = average, 1 = weak.

[cd]Means for a given trait without a common superscript are significantly different (P $<$ .05).

Cellulolytic Bacteria from Gestating Swine Fed Various Levels of Dietary Fiber

Vincent H. Varel and Wilson G. Pond[1]

Introduction

Recent studies have shown that the number and activity of cellulose degrading bacteria in the large intestine of growing-finishing pigs increase when a high fiber diet, such as 50 percent alfalfa meal, is fed. This suggests that the bacterial flora adapts to dietary fiber as the animal matures. Two of the predominant cellulolytic species found in the rumen have been shown to be predominant organisms in the large intestine of the pig. Thus, the potential exists for significant quantities of cellulose to be degraded in the large intestine of the pig. Various studies provide evidence that pigs obtain nutrients from fiber added to their diet. Fibrous material, primarily cellulose and hemicellulose, is degraded to volatile fatty acids by microbial enzymes in the large intestine. The volatile fatty acids are absorbed by the animal and used for part of the animal's energy requirement. Estimates indicate that 4.8, 11.4, 14.0, and 12 percent of the maintenance energy can be obtained from absorption of volatile fatty acids from the large intestine when growing-finishing pigs are fed 0, 20, 40, and 60 percent alfalfa meal, respectively. Twenty to forty percent alfalfa meal (> 25 pct cell walls) can be fed to growing pigs without seriously reducing growth.

Research with sows indicates that 96 percent alfalfa meal can be fed through three reproductive cycles with normal reproductive performance occurring. The residence time of ingesta in the sow is longer than that of a growing pig because of the sow's larger size; thus, one might expect an increase in the cellulolytic flora. If the sow's reproductive performance is not sacrificed by high levels of fiber in the diet and, if a high concentration of cellulolytic organisms exist in the large intestine, the sow may be the preferred animal for feeding high fiber diets rather than the growing pigs, which is growth-limited by the energy provided. The objectives of our studies were to determine the number and activity of the cellulolytic bacteria present in the large intestine of gestating sows which were fed either a control diet, 20 percent corn cob, 40, or 96 percent alfalfa meal.

Procedure

Twenty primiparous 4-way cross (Chester White x Landrace x Large White x Yorkshire) gilts were assigned on the day of breeding to one of the four gestation diets (5 pigs per diet) indicated above. Number and activity of cellulose-digesting bacteria from rectal samples were determined at 0, 5, 14, 21, 35, 49, 70, and 98 days after feeding the experimental diets.

Results

The cell walls or fiber contents in the control diet, 20 percent corn cobs, 40, and 96 percent alfalfa meal were 15, 27, 27, and 40 percent, respectively. The number of cellulolytic bacteria from fecal samples increased with an increasing concentration of fiber or plant cell walls in the diets, with the exception of the 20 percent corn cob diet (Table 1). When the corn cobs served as the fiber source, the number of cellulolytic bacteria was less than the control, although not significantly. It should be noted that all pigs on day 0 were fed the control diet, and the number of cellulolytic bacteria was not different between each group of 5 pigs. However, after 7 additional samples were obtained from the pigs on their respective diets over a period of 98 days, significant differences were observed overall when the pigs fed the control and 20 percent corn cobs were compared to the pigs fed 40 and 96 percent alfalfa meal. Considerable animal-to-animal variability was observed; however, a trend toward higher numbers of cellulolytic bacteria was evident after feeding 40 and 96 percent alfalfa meal over a period of time.

Table 1.—Number of cellulolytic bacteria from fecal samples of sows fed diets containing various levels of fiber

Time on diet (days)	Cellulolytic bacteria (x 10^8 g dry wt)			
	Diet			
	Control	20 pct corn cobs	40 pct alfalfa	96 pct alfalfa
0	14.7	6.0[a]	10.8[a]	14.1[a]
5	10.1	10.2	34.4	56.5
14	22.4	17.5	18.8	24.2
21	28.4	16.9	41.3	71.0
35	27.8	16.3	105.3	54.9
49	24.6	32.8	43.5	76.3
70	25.0	9.3	56.5	59.3
98	33.3	12.5	50.2	63.7
Overall	23.3[b]	15.2[b]	45.1[c]	52.5[d]

[a]Control diet was fed until initiation of experiment.

[bcd]Overall means without a common superscript differ (P <.05).

The activity of the cellulolytic bacteria, expressed as cellulase activity (Table 2), did not directly parallel the number of cellulolytic bacteria (Table 1) as one might expect. The cellulase activity of pigs fed the 20 percent corn cob diet overall was 19.9, as expressed by a cellulolytic population of 15.2×10^8 organisms per gram. The cellulase activity obtained from the control diet was 17.0 (23.8×10^8 organisms per gram), which is obviously smaller than 19.9, yet more organisms are present. This apparent contrasting relationship, where a smaller number of cellulolytic organisms gives a greater cellulolytic activity, is again seen when the values for 40 and 96 percent alfalfa meal are compared. This lack of correlation between number of cellulolytic bacteria and cellulase activity may be related to different species of cellulolytic bacteria that are involved in the breakdown of the various diets. We have previously isolated two different species of cellulolytic organisms from intestinal samples of growing-finishing pigs: *Bacteroides succinogenes*, which contains a cell-bound cellulase, and *Ruminococcus flavefaciens*, which produces an extracellular cellulase.

We did see some consistency between the number and activity of cellulolytic bacteria from the adult pigs fed 40 percent alfalfa meal in this study and growing-finishing pigs fed 35 percent alfalfa meal in a previous study we have conducted. Both studies showed an increase in number and activity of cellulolytic bacteria over the control animals when alfalfa meal was fed. In comparing the two studies between the adult and growing pigs, of interest was the 6.7-fold greater number of cellulolytic organisms found in the fecal samples of the adult pigs than the growing-finishing pigs. Possibly, this may be one reason for the general observation that the adult pig has a greater potential to digest cellulosic material and can adequately maintain itself on all-forage diets. The residence time of ingesta in the adult animal is longer due to the larger size of the intestinal tract, which would support more extensive degradation of fiber.

In the present study, the number of live pigs born was not different between diet treatments, although the live birth weights from gilts fed 96 percent alfalfa meal were less. Part of this lower birth was due to a lower daily consumption of feed by the pigs fed 96 percent alfalfa meal. Prepartum weight gain was 112, 98, 96, and 7 lb for the gilts fed the control, 20 percent corn cobs, 40, and 96 percent alfalfa meal, respectively.

In summary, it appears that the microflora in the pig large intestine can be manipulated by high forage diets. The microflora apparently shifts to a larger population of cellulolytic organisms in response to prolonged feeding of high fiber diets. This indicates some potential for adapting the monogastric animal to utilize feedstuffs other than cereal grains, which are used by man. The preferred age of pigs to be fed high fiber diets is the adult, because we are interested in maintaining a constant weight, in comparison to a growing-finishing pig in which we desire a high energy diet primarily for growth.

Table 2.—Cellulase activity from fecal samples of sows fed diets containing various levels of fiber

| Time on diet (days) | Cellulase activity (mg glucose released/g dry wt per 30 min) | | | |
| | Diet | | | |
	Control	20 pct corn cobs	40 pct alfalfa	96 pct alfalfa
0	15.9	15.5[a]	15.2[a]	14.3[a]
5	15.3	18.4	21.2	23.0
14	17.9	20.3	21.9	16.5
21	17.2	21.3	25.1	21.5
35	18.4	21.5	25.9	20.0
49	19.4	21.5	23.7	23.6
70	16.3	20.5	28.0	22.7
98	15.8	20.2	29.6	23.6
Overall	17.0[b]	19.9[c]	23.8[d]	20.6[c]

[a]Control diet was fed until initiation of experiment.

[bcd]Overall means without a common superscript differ (P <.05).

Raw Soybeans in Sow Diets

Jong-Tseng Yen and Wilson G. Pond[1]

Introduction

Recent research has shown that the addition of fat or vegetable oil to sow diets during late gestation and(or) lactation improves the survival rate of the weak and smaller piglets. However, this beneficial effect of supplemental dietary fat has been hindered by practical problems associated with obtaining, storing, handling, and mixing the fat into the diet. These problems may be solved by utilizing special bulk fat holding tanks and good mixing facilities which can only be considered by large operations or by using more expensive, newly developed dry fat products which can be stored and handled like any other feed ingredient. Soybean meal, the major protein supplement for swine, is derived from processing soybeans for edible oil. Raw soybeans contain about 18 percent oil, can be stored and handled like soybean meal or other common feed ingredients and, thus, could be a less costly source for providing supplemental fat to sow diets. This potential for raw soybeans has not been widely recognized because it is well known that raw soybeans also contain antinutritional factors which retard growth in swine. Nevertheless, the response of swine to the antinutritional factors in raw soybeans may be influenced by age of the animal, as is the case in the rat and chicken. Indeed, raw soybeans appear to have no detrimental effect on the reproductive performance of gestating swine. Illinois researchers observed that, for sows fed a gestation diet containing either raw soybeans or soybean meal, litter sizes and pig weights at birth and weaning were similar even though sows fed raw soybeans gained less weight than those fed soybean meal.

Recent Nebraska studies, however, showed no difference in weight gain of sows fed raw soybeans during gestation. They further reported an improved pig survival rate in the first parity from sows fed raw soybeans, probably as a result of the high oil content of raw soybeans. Higher energy intake during lactation reduces the number of sows that show a prolonged interval from weaning to estrus and may improve the overall reproductive efficiency of a swine herd. The purpose of this research was to evaluate the effect of raw soybeans or supplemental soybean oil in gestation and lactation diets on sow and litter performance through two parities.

Procedure

Thirty-four gilts (264 lb average weight) were bred and assigned to three dietary treatments (Table 1). Diet 1 was a corn-soybean meal diet formulated to contain 14 percent crude protein; diet 2 was a corn-raw soybean diet formulated to 14 percent protein and containing 20.1 percent of raw soybeans; diet 3 was a corn-soybean meal diet formulated to contain 14 percent protein and 2 percent supplemental soybean oil, and thus was isocaloric to diet 2. Corn and raw soybeans were ground with a one-fourth in screen. The same batch of soybean meal and of raw soybeans was used throughout the entire experiment. The raw soybeans were assayed to contain 27.6 parts per million (ppm) of trypsin inhibitor and the soybean meal contained 2.4 ppm of trypsin inhibitor. Antioxidant (ethoxyquin) was added to diets at an amount of 6 oz per ton of feed.

The experiment was conducted through two parities. The animals were housed in individual stalls and fed 4 lb a day until day 108 of gestation. They were moved on day 108 and kept in farrowing crates until 28 days after farrowing. They were fed 4 lb daily until farrowing and then *ad*

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[1]Yen is a research animal scientist and Pond is the research leader, Nutrition Unit, MARC.

Table 1.—Composition of diets

Ingredients	Diet		
	Soybean meal	Raw soybeans	Soybean meal + soybean oil
	Percent		
Ground corn	81.1	75.9	78.6
Soybean meal (46.2 pct C.P.)	14.9	--	15.4
Raw soybeans (36.5 pct C.P.)	--	20.1	--
Soybean oil	--	--	2.0
Dicalcium phosphate	2.0	2.0	2.0
Limestone	0.8	0.8	0.8
Iodized salt	0.4	0.4	0.4
Trace mineral premix	0.4	0.4	0.4
Vitamin premix	0.2	0.2	0.2
Choline chloride[a]	0.1812	0.1812	0.1812
Antioxidant[b]	0.0188	0.0188	0.0188
Calculated analysis			
C.P., pct	14.02	14.02	14.03
Ca, pct	0.80	0.81	0.80
P, pct	0.69	0.70	0.69
ME, kcal/lb	1,435	1,470	1,470

[a]Contains 50 percent choline.
[b]Santoquin mixture 6.

libitum during the lactation period. Between days 13 and 15 of lactation, milk samples were obtained from udder sections 1 and 3 from the front of each sow for the determination of milk protein and fat. Pigs were weaned at 28 days of age. Upon weaning, sows were returned to individual gestation stalls, fed 4 lb a day, checked for estrus by using boars, and rebred at first estrus. Days from weaning to estrus after both parities and conception rate were recorded. Sows were weighed at breeding, at 112 days of gestation, at farrowing, and at weaning. Pigs were weighed at birth, at 21 days of age, and at weaning. Mortality of pigs from birth to weaning and feed consumption of sows during gestation and lactation were recorded.

Results

The effect of raw soybeans and supplemental soybean oil in gestation and lactation diets on litter performance through two parities are summarized in Table 2. Neither raw soybeans nor supplemental soybean oil had any significant effect on the number of pigs born alive, survival rate of pigs from birth to weaning at 28 days of age, pig weights at birth and at weaning, or litter weights at birth and at weaning. The relatively high survival rate of piglets (more than 91 pct) in the present study may be one reason why additional oil from raw soybeans and supplemental soybean oil failed to elicit any improvement, because on-ly if the herd survival rate is less than 80 percent is the survival rate among the piglets likely to be increased by supplemental dietary fat in sow diets.

As shown in Table 3, when compared with sows fed a soybean meal diet with or without supplemental soybean oil, sows fed raw soybeans in the first parity tended to gain less weight during gestation and lose more weight during lactation. They also ate significantly less feed during lactation and produced milk containing a significantly higher percentage of fat. The number of first parity sows returned to estrus and the interval from weaning to estrus did not differ among sows fed different diets. In the second parity, there were no significant dietary treatment effects on sows in affecting lactation weight change, lactation feed intake, percentage of milk fat, number of sows returned to estrus, and the interval from weaning to estrus. However, sows fed raw soybeans had a significantly lower percentage of milk protein than did sows fed soybean meal diets.

The findings of this research substantiate previous studies and indicate that raw soybeans can be used in diets for gestating and lactating swine without affecting sow and litter performance through two parities. Nevertheless, further research is needed to fully investigate the possibility of using raw soybeans as a supplemental dietary energy source for improving survival rate of piglets in herds with less than 80 percent survival rate.

Table 2.—Effect of raw soybeans and supplemental soybean oil in gestation and lactation diets on litter performance[a]

| | Diet | | |
Item	Soybean meal	Raw soybeans	Soybean meal + soybean oil
Parity 1			
Litter farrowed	10	8	10
No. pigs born alive	8.6	8.3	10.6
No. pigs alive at 28 days	8.0	7.6	9.6
Survival rate at 28 days, pct	93.9	91.7	91.1
Pig wt at birth, lb	3.2	3.2	3.0
Pig wt at 28 days, lb	15.0	13.9	13.2
Litter wt at birth, lb	27.2	25.9	31.7
Litter wt at 28 days, lb	114.7	100.5	123.2
Parity 2			
Litter farrowed	7	6	7
No. pigs born alive	7.9	8.8	10.3
No. pigs alive at 28 days	7.1	8.8	9.4
Survival rate at 28 days, pct	93.3	100.0	92.1
Pig wt at birth, lb	3.3	3.3	3.2
Pig wt at 28 days, lb	16.6	13.8	14.1
Litter wt at birth, lb	24.2	28.8	32.8
Litter wt at 28 days, lb	110.4	119.2	131.1

[a]No significant (P>0.05) differences in the described criteria for litter performance could be detected among three dietary treatments.

Table 3.—Effect of raw soybeans and supplemental soybean oil on sow weight changes, feed intake, milk protein, milk fat, number returned to estrus, and interval from weaning to estrus

| | Diet | | |
Item	Soybean meal	Raw soybeans	Soybean meal + soybean oil
Parity 1			
No. bred	11	11	12
No. farrowed	10	8	10
Gestation wt change, lb	133.8	121.4	138.4
Lactation wt change, lb	-40.9	-56.5	-50.6
Lactation feed intake, lb[a]	228.8	199.1	232.8
Milk protein, pct	5.2	4.9	5.3
Milk fat, pct[a]	7.8	9.2	8.4
No. returned to estrus	9	6	8
Days from weaning to estrus	6.0	4.3	4.8
Parity 2			
No. bred	9	6	8
No. farrowed	7	6	7
Lactation wt change, lb	-38.7	-45.8	-44.2
Lactation feed intake, lb	241.3	232.3	270.8
Milk protein, pct[b]	4.9	4.2	4.8
Milk fat, pct	6.8	6.7	7.2
No. returned to estrus	5	6	7
Days from weaning to estrus	8.4	5.2	4.3

[a]Significant treatment effect (P<0.05).
[b]Significant treatment effect (P<0.01).

Measuring Net Absorption of Nutrients from the Gastrointestinal Tract in Conscious Swine

Jong-Tseng Yen and John Killefer[1]

Introduction

The difference in concentrations of a nutrient in blood before and after its passing through the gastrointestinal circulation reflects the net uptake from, or loss to, the gastrointestinal tract and is a more critical measurement for nutrient availability than is the digestibility determination which measures the disappearance of a nutrient from the gastrointestinal tract. The hepatic portal vein carries the blood coming from the stomach, the intestinal tract, the pancreas, and the spleen, and it is the major pathway for transporting the nutrients absorbed from the gastrointestinal tract (with the exception of long-chain fatty acids, which are carried in the lymph and enter the thoracic duct). By multiplying concentration differences of a nutrient between the efferent (portal) and afferent (systemic arterial) blood by the simultaneously determined portal blood flow rate, the net nutrient absorption into the portal vein per unit of time (for example, mg of glucose per minute) can be estimated.

This research was directed toward developing surgical and laboratory procedures for collecting blood samples from hepatic portal vein and systemic artery and for simultaneous measurement of portal vein blood flow rate in conscious swine. With these procedures, the net quantity of a nutrient which is absorbed and will be available to the animal can then be estimated.

Procedure

Surgical technique. Growing crossbred gilts weighing 61 lb were first housed in individual cylindrical metabolism cages and trained to consume their daily feed allowance in a single meal. Five to 6 weeks later, they were transferred to individual pens and further trained to adapt to rectangular metabolism cages for subsequent infusion and blood sampling studies. Following a 24-h fast, each pig was anesthetized with a sodium thiopental injection via anterior vena cava and then placed under closed-circuit anesthesia with halothane in oxygen.

Each pig was placed on her left side. An incision was made approximately 1 in behind and parallel to the last rib on the right side of the animal. The portal vein was located and cannulated with polyurethane tubing. Through the same incision, the ileal vein was also located and cannulated with silastic tubing. The incision was closed after both the portal and ileal vein cannulas were exteriorized to the upper right side of the pig.

The abdominal aorta or carotid artery had been cannulated for sampling systemic arterial blood. The pig was placed on its back. For cannulating the abdominal aorta, a vinyl tubing was inserted into the saphenous artery for about 10 to 11 in, so its tip would travel through femoral and external iliac arteries and rested within the abdominal aorta. The cannula was exteriorized to the right flank of the pig through a subcutaneous tunnel made by a trocar. For cannulating the carotid artery, an incision was made over the larynx to locate and expose the right carotid artery.

A polyurethane cannula was inserted into the carotid artery for approximately 6 in and exteriorized to the right side of the neck.

The portal vein, ileal vein, abdominal aorta, or carotid artery cannulas were further exteriorized through a subcutaneous tunnel and rested about 1 in below the midline of animal's back. The cannulas were fitted with proper sized needle adapters, flushed, filled with heparinized saline solution, and capped with plugs. The adapters and plugs were wrapped with elastic tape to prevent damage.

Measurements of the rate of portal vein blood flow and of the net portal absorption of glucose. Each pig was weighed and placed into the rectangular metabolism cage at 3:30 p.m. At 7:25 a.m. of the next day, the pig was primed and then continuously infused with a constant rate of p-aminohippuric acid (PAH) for the next 8½-h via the ileal vein cannula (Fig. 1). A 16 percent protein corn-soybean meal standard grower diet was mixed with equal volume of water and fed to the pig at 8:30 a.m. after the 24-h fast. Blood samples were taken from both the portal vein and abdominal aorta or carotid artery every 30 min from 30 min before to 4 h after feeding and then hourly during the 4 to 8 h after feeding periods.

Results

The entire surgery took about 4 h. In 13 pigs, the time required for the operated animals to resume their preoperative appetite ranged from 2 to 15 days. The duration that all three cannulas were patent ranged from 7 to 64 days. It was extended for another 15 to 42 days when a new portal vein cannula was inserted to replace the nonfunctioning cannula or the carotid artery was cannulated to substitute the blocked abdominal aorta cannula.

The portal vein blood flow rate of the pigs was estimated by the continuous infusion indicator dilution technique

Table 1.—Portal vein blood flow rate (PVBF) and net portal absorption of glucose in pigs

Body weight, lb	
Range	72.6
Average	118.8
PVBF (ml/min)	
Preprandial	1,522
Postprandial	1,979
Glucose absorption (mg/min)	
Preprandial	160
Postprandial	726
PVBF (ml/min/lb body wt)	
Preprandial	13.4
Postprandial	17.2
Glucose absorption (mg/min/lb body wt)	
Preprandial	1.3
Postprandial	6.0

employing PAH as the indicator. As shown in Table 1, for 13 pigs with body weight ranging from 73 to 187 lb, the portal vein blood flow rate during the preprandial (before feeding) and postprandial (after feeding) periods were 1,522 and 1,979 ml/minute, respectively. The net absorption of glucose into the portal blood were 160 and 726 mg/minute, respectively, for the pre- and postprandial periods. When expressed on a per-pound body weight basis, the portal vein blood flows for the pre- and postprandial periods were 13.4 and 17.2 ml/min/lb, respectively. A 17.1 ml/min/lb liveweight postprandial portal vein blood flow rate has been reported for pigs weighing between 90 and 139 lb by French researchers who used an electromagnetic blood flow probe for the measurement. This value is almost identical to that obtained in the present research. The net portal absorption of glucose in our pigs was 1.3 and 6.0 mg/min/lb body weight, respectively, for the pre- and postprandial periods.

Besides measuring the uptake of nutrients from the gastrointestinal tract, the procedures developed in this research can also be used to determine the absorption of gastrointestinal metabolites such as noxious ammonia produced by intestinal microbia and volatile fatty acids produced from the fermentation of carbohydrates and fibrous diets.

Figure 1—A pig with carotid artery, portal vein, and ileal vein cannulas (from front to rear) and under infusion.

The Response of Weanling Pigs to Vitamin C or Carbadox

Jong-Tseng Yen and Wilson G. Pond[1]

Introduction

Pigs are generally assumed to be able to synthesize enough vitamin C for normal growth and development. However, there is evidence that supplemental vitamin C occasionally may improve the performance of pigs. Like pigs, chickens also can synthesize vitamin C and do not require dietary vitamin C supplementation. However, when chicks were infected with fowl typhoid or intestinal coccidiosis, their plasma vitamin C concentration was reduced. In a previous study, a decline in plasma vitamin C concentration was observed in young pigs after weaning, and dietary vitamin C supplementation increased both the plasma vitamin C level and weight gain. It was suggested that the beneficial response from supplemental vitamin C with weanling pigs might have been related to suppression of postweaning subclinical disease caused by the decreased plasma vitamin C concentration and the dramatic changes in nutritional, social, and other environmental factors associated with weaning. Suppression of subclinical disease also is a proposed mode of growth promotion of subtherapeutic levels of antimicrobial agents. During periods of infection in man, the blood level of iron generally decreases while that of ceruloplasmin (a copper-containing enzyme) increases. The objective of this research was to determine the effect of carbadox, a synthetic growth promoting antimicrobial agent and vitamin C, added either singly or in combination, on performance and plasma concentrations of vitamin C, iron, and ceruloplasmin in weanling pigs.

Procedure

A factorial arrangement with two levels of supplemental vitamin C (0 or 660 ppm as L-ascorbic acid) and two levels of carbadox supplementation (0 or 55 ppm as Mecadox) was used in two experiments with 112 crossbred (Chester White x Landrace x Large White x Yorkshire) weanling pigs. An 18 percent protein corn-soybean meal-oats-dried whey starter diet was used as the basal diet. Each of the four test diets were self-fed for 4 weeks to three replicates of four pigs each (16.1 lb average initial weight) in experiment 1, and to four replicates of four pigs each (15.6 lb average initial weight) in experiment 2.

In each experiment the pigs were weaned between 4 and 5 weeks of age and moved immediately to an environmentally regulated nursery with expanded metal floor. The pens measured 3 x 8 ft. Pig weight and feed consumption were recorded weekly. A blood sample was taken at the outset of the trial and at weekly intervals. Plasma was assayed for vitamin C, iron, and ceruloplasmin.

Results

Experiment 1. Effects of dietary supplementation of vitamin C or carbadox on cumulative average daily weight gain, daily feed, gain to feed ratio, and plasma concentrations of both vitamin C and iron in pigs are summarized in Table 1. Cumulative daily gain, daily feed intake, and gain to feed ratio of pigs were improved significantly by dietary supplementation of carbadox but not by vitamin C. Significant interaction of vitamin C and carbadox supplementation in affecting daily feed intake was observed on both days 14 and 28 of the test. Vitamin C reduced daily feed intake in the absence of carbadox but increased it in the presence of carbadox. Compared with the initial value, plasma vitamin C concentration of pigs fed the basal diet was significantly reduced up to day 21 of the test. However, on day 28, plasma vitamin C level was similar to that at the outset of the experiment. Dietary supplementation of vitamin C or carbadox increased significantly plasma vitamin C concentration on day 14 but not on day 28 of the test. Plasma iron concentration on day 28 was significantly higher in pigs fed carbadox supplemented diets than in those not fed this antimicrobial agent. Vitamin C supplementation had no effect on plasma iron concentration of pigs.

Experiment 2. As shown in Table 2, supplementation of carbadox but not vitamin C significantly improved the average daily gain of weanling pigs. Carbadox supplementation also produced significantly greater daily feed intake on day 28 and higher gain to feed ratio on day 14 of the test. On both days 14 and 28, plasma vitamin C concentration was increased by supplementation with vitamin C or carbadox, while significantly higher plasma iron level was produced by supplemental carbadox but not by vitamin C. Plasma ceruloplasmin concentration in pigs increased after weaning. This increase could not be prevented by supplemental vitamin C or carbadox.

The results of these two experiments agreed with our previous study and showed that dietary supplementation of 660 ppm vitamin C increased plasma vitamin C concentration in weanling pigs. However, unlike our previous results, supplemental vitamin C in the present study did not improve weight gain of pigs. The failure of supplemental vitamin C to improve weight gain of weanling pigs in the present study cannot be attributed to full expression of growth potential in pigs fed the basal diet, because carbadox supplementation caused a significant improvement in weight gain. Carbadox supplementation also produced an increase in plasma concentration of vitamin C and iron. The high plasma vitamin C level in the pigs fed carbadox may have been caused by the increased vitamin C synthesis as a by-product of glucuronic acid production, induced by the xenobiotic effect of carbadox. The higher plasma iron concentration and the greater weight gain in pigs fed carbadox may reflect a less severe level of postweaning subclinical infection, in view of the observation in humans that virtually all infectious processes depress plasma iron concentration. The significantly increased plasma ceruloplasmin observed in pigs of experiment 2 during the postweaning period also suggests the possibility of a subclinical infection, because elevated plasma ceruloplasmin has been reported as a phenomenon commonly associated with chronic and acute infectious diseases.

[1]Yen is a research animal scientist and Pond is the research leader, Nutrition Unit, MARC.

Table 1.—Effect of dietary supplementation of vitamin C or carbadox on cumulative average daily gain, daily feed, and gain to feed ratio and on plasma vitamin C and iron of pigs in experiment 1

Item	Basal	Vitamin C	Carbadox	Vitamin C + carbadox	Statistical significance[a]
Diet					
Avg daily gain, lb[b]					
Day 14	.38	.32	.48	.60	Carb
Day 28	.69	.69	.82	.85	Carb
Avg daily feed, lb[b]					
Day 14	1.02	.77	.99	1.10	Carb; Vit C x Carb
Day 28	1.64	1.45	1.64	1.74	Carb; Vit C x Carb
Gain to feed ratio[b]					
Day 14	.37	.42	.48	.54	Carb
Day 28	.42	.47	.50	.49	Carb
Plasma vitamin C, mg/dl[c]					
Initial	2.07[d]	1.98	2.01	2.02	NS
Day 14	1.50[e]	1.59	1.59	1.86	Vit C; Carb
Day 28	1.88[d]	2.11	1.96	2.00	NS
Plasma iron, μ g/dl[c]					
Initial	165	161	144	149	NS
Day 14	133	150	156	176	NS
Day 28	154	155	179	173	Carb

[a]Treatment effects: NS = nonsignificant; Vit C = supplemental vitamin C effect; Carb = supplemental carbadox effect; Vit C x Carb = interaction between vitamin C and carbadox supplementation (P<0.05).
[b]Values are means for three replicates of 4 pigs each with 16.1 lb average initial weight.
[c]Values are means for 12 pigs.
[de]Means for each trait in the same variable column with different superscripts differ significantly (P<0.05).

Table 2.—Effect of dietary supplementation of vitamin C or carbadox on cumulative average daily gain, daily feed, and gain to feed ratio and on plasma vitamin C, iron, and ceruloplasmin of pigs in experiment 2

Item	Basal	Vitamin C	Carbadox	Vitamin C + carbadox	Statistical significance[a]
Diet					
Avg daily gain, lb[b]					
Day 14	.49	.50	.66	.65	Carb
Day 28	.76	.75	.93	.96	Carb
Avg daily feed, lb[b]					
Day 14	.95	1.18	1.15	1.11	NS
Day 28	1.65	1.67	1.99	2.01	Carb
Gain to feed ratio[b]					
Day 14	.52	.44	.58	.58	Carb
Day 28	.46	.45	.47	.48	NS
Plasma vitamin C, mg/dl[c]					
Initial	1.49[d]	1.50	1.51	1.53	NS
Day 14	1.43[d]	1.53	1.51	1.69	Vit C; Carb
Day 28	1.67[e]	1.90	1.94	2.24	Vit C; Carb
Plasma iron, μ g/dl[c]					
Initial	94[d]	116	97	110	NS
Day 14	141[e]	136	148	163	Carb
Day 28	150[e]	152	171	185	Carb
Plasma ceruloplasmin, units/ml[c]					
Initial	45[d]	46	46	42	NS
Day 14	60[e]	71	66	68	NS
Day 28	86[f]	79	77	78	NS

[a]Treatment effects: NS = nonsignificant; Vit C = supplemental vitamin C effect; Carb = supplemental carbadox effect (P<0.05).
[b]Values are means for four replicates of 4 pigs each with 15.6 lb average initial weight.
[c]Values are means for 16 pigs.
[def]Means for each trait in the same variable column with different superscripts differ significantly (P<0.05).

Estimation of Body Composition of Pigs

Calvin L. Ferrell and Steven G. Cornelius[1]

Introduction

The interpretation of many experiments that alter or assess animal growth could be enhanced by the determination of the rate and efficiency of accretion of the various chemical constituents that account for the increase in body mass. An ideal technique for measurement of body composition should be accurate, easily accomplished, inexpensive, applicable to a wide range of ages and compositions, and capable of being applied to the live animal with minimal perturbation of subsequent performance. Whole body analysis or dissection into component parts is rigorous but fails in the other categories. Thus, several alternative procedures have been suggested to estimate body composition.

Dilution techniques estimate either total or empty body water, which is then used to predict body composition. They are nondestructive and, thus can be used in the live animal. The most attractive of these appears to be the utilization of deuterium oxide (D_2O) because of its accuracy, ease of determination, and marketability of treated animals. The purposes of this study were to evaluate the use of D_2O as a method to estimate body composition and to characterize growth of congenitally obese and contemporary (Hampshire X Yorkshire) pigs in terms of growth patterns of the various body chemical components.

Procedure

Crossbred (Duroc X Yorkshire) high-fat (Ob) and contemporary (C; Hampshire X Yorkshire) pigs were chosen as representatives of populations with widely different genetic propensities to deposit body fat. Castrated males and female pigs were chosen from each of eight litters of each type (30 pigs total of each type) and assigned at random, within sex, litter, and type to each of five groups. The five groups of six pigs of each type were later infused with D_2O and subsequently killed at 4, 8, 12, 18, and 24 weeks

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of age as detailed below. All pigs were housed and raised under standard confinement management practices.

Two days before D_2O was to be infused, a catheter was inserted into a jugular vein. Pigs were then moved to crates and housed individually. The D_2O was infused (.23 cc/lb liveweight) into the jugular catheter of each pig. Blood samples were drawn from the catheter immediately before and .25, 1, 4, 8, 12, 24, and 48 h after the D_2O infusion. Each pig was killed immediately after the 48-h blood sample was taken. Total weight was recorded. Each pig was then eviscerated, and digesta were removed from the gastrointestinal tract. Empty body (digesta free) weight was recorded. The total empty body of each pig was frozen and later ground. The ground material was mixed and samples were taken, weighed, and then stored frozen until analyzed.

All tissue samples were analyzed for dry matter. Water was calculated as the difference between the fresh ground sample weight and dry weight. Fat and protein were determined and the D_2O concentration in each blood sample was determined. Regressions between D_2O concentrations (Y) in blood water and time postinjection (t) were developed for each animal. The D_2O space was then calculated from the intercept value and the amount of D_2O infused.

Results

None of the weights of the body components measured (Table 1) differed between the two types of pigs at 4 or 8 weeks of age, but trends were similar to those observed at older ages. The C pigs had more liveweight, empty body weight, water, D_2O space, and protein but less fat than Ob pigs at 12 and 18 weeks. At 24 weeks, C pigs had lower live, empty body, and fat weights but greater water and protein weights, and D_2O space.

Relationships between weight of body components and age (Table 2) are presented to show the accretion pattern of the various body components for each pig type. Regression of empty body water or protein weight on age did not differ significantly due to pig type. These results suggest accretion rates of these body components did not differ

Table 1.—Least-squares means for liveweight, empty body weight, and weight of gross chemical empty body components of obese and contemporary pigs

Type	Age, wk	No. of pigs	Liveweight, lb	Empty body component (lb)				D_2O space, lb
				Total weight	Water	Fat	Protein	
Obese	4	4	11.0	10.1	6.8	1.3	1.6	7.8
	8	3	23.4	21.6	14.4	3.1	3.9	16.3
	12	6	58.6	54.7	31.7	12.8	8.6	37.0
	18	6	119.9	111.3	55.6	36.8	15.0	66.4
	24	6	203.3	193.6	75.8	89.9	23.1	85.5
Contemporary	4	5	17.5	17.1	11.9	1.7	3.0	14.2
	8	6	30.9	29.3	20.5	3.0	4.8	24.5
	12	6	73.2	69.0	45.4	9.9	11.9	51.1
	18	6	149.5	139.3	83.6	26.9	24.5	104.5
	24	6	184.7	180.6	99.0	45.8	30.2	120.2
SE			1.98	1.74	1.04	.73	.29	1.87

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substantially between the two types of pigs. Relationships between liveweight, empty body weight, or fat and age indicated rates of gain of these components differed between pig types. These results show the major difference in the pattern of growth of C and Ob pigs was in the amount of growth rate of body fat. These differences resulted in the Ob pigs having nearly twice as much body fat at 24 weeks as C pigs.

Total liveweight was highly related to empty body weight (Table 3) and the relationship was not influenced by pig type. These results suggested empty body weight was predictable from liveweight. All relationships between body chemical components and liveweight were influenced by pig type; thus, regressions were presented for each type of pig. Because of the high correlation between liveweight and empty body weight, similar results were obtained when empty body weight, rather than liveweight, was used as the independent variable (data not presented). These results show that, within pig type, weights of body chemical components are highly related to liveweight, but liveweight or empty body weight had little value for the prediction of weight of body components when animals of divergent genotypes were included.

Regressions of weight of various body chemical components on D_2O space and liveweight for Ob and C pigs are presented in Table 4. The regression coefficients for D_2O space differed from zero for the Ob pigs but were not significant for C pigs. These results suggest that weight of body components in Ob pigs were predicted with greater accuracy using D_2O space and liveweight than by using liveweight alone. However, in C pigs accuracy of prediction of weight of body components was not improved by the inclusion of D_2O space, in addition to liveweight, as an independent variable.

Numerous researchers have concluded that body water may be used to predict the body composition of mammals accurately. The results of this study also demonstrated that weight of body water is highly and positively correlated to weight of nonfat body tissues, and percentage body water is highly and negatively associated with percentage body fat. However, the accuracy of estimation of body composition by water dilution procedures depends upon an accurate assessment of body water as well as on the relationship of body water to other body components.

Data presented in Table 1 show that D_2O space was 18.8 percent greater than actual empty body water in this study. Presumably, a consistent overestimate of body water from D_2O spaced can be overcome by regression of actual body water on D_2O space. In this study, however, both the intercept (-.22 ± .69 vs 2.49 ± 1.55; P = .15) and the slope (.87 ± .03 vs. .74 ± .04, P = .05) of this relationship tended to differ between Ob and C pigs.

We conclude that, because of the differing relationships between D_2O space and body water, the use of deuterium dilution to estimate body water is unlikely to enable accurate estimation of body composition of animals of very divergent genotypes. Results of others also suggest that considerable caution is necessary in the application of deuterium dilution techniques to animals of differing physiological states or of differing nutritional histories.

Table 2.—Relationships between weight of various body components and age of obese and contemporary pigs

Type	No. of pigs	Component (lb)	b_0		b_1		b_2		R^2
Obese	25	Liveweight	-.64	± 11.7	1.08 ± 1.85		1.68	± .14	.97
		Empty body weight	-2.01	± 10.3	.49 ± 1.63		.68	± .12	.97
		Empty body water	-10.4	± 3.3	3.59 ± .20				.93
		Empty body fat	-11.9	± 5.0	3.44 ± .79		.610	± .058	.97
		Empty body protein	-4.10	± .93	1.12 ± .057				.94
Contemporary	29	Liveweight	-31.3	± 6.8	9.22 ± .44				.94
		Empty body weight	-30.6	± 5.7	8.88 ± .37				.95
		Empty body water	-11.1	± 3.4	4.78 ± .22				.94
		Empty body fat	-.029	± 3.4	.17 ± .55		.19	± .044	.95
		Empty body protein	-5.09	± 1.01	1.50 ± .07				.95

[a]Model was $Y = b_0 + b_1 + b_2X^2$ where Y = weight of component (lb) and X = age in weeks.

Table 3.—Relationships between liveweight and weight of the total empty body on empty body gross chemical components

Type	No. of pigs	Empty body Component (lb)	b_0		b_1		b_2		R^2
All	54	Weight	1.36	± .619	.948 ± .012				.99
Obese	25	Water	1.34	± 1.03	.52 ± .05		-.0016	± .0005	.97
		Fat	-1.29	± 1.35	.23 ± .07		.0022	± .0006	.97
		Protein	.23	± .26	.144 ± .013		-.00034	± .00012	.98
Contemporary	29	Water	-.13	± 1.03	.72 ± .06		-.0022	± .0006	.98
		Fat	.63	± .79	,023 ± .04		.0024	± .0005	.96
		Protein	.094	± .190	.161 ± .004				.99

[a]Model was $Y = b_0 + b_1X + b_2X^2$ where Y = weight of component and X = liveweight, lb.

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Table 4.—Relationships of weight of empty body chemical components to D_2O space and liveweight in obese and contemporary pigs

Type of pig[a]	Dependent variable (lb)	Regression coefficients[b]			R^2
		b_0	b_1	b_2	
Obese	Water	.7 ± .7	.63 ± .09	.10 ± .04	.98
	Fat	-.7 ± 1.0	-.81 ± .13	.78 ± .05	.98
	Protein	.05 ± .18	.14 ± .02	.053 ± .010	.99
Contemporary	Water	2.4 ± .8	.088 ± .077	.46 ± .05	.98
	Fat	-2.2 ± .7	-.081 ± .068	.30 ± .05	.93
	Protein	.06 ± .20	.016 ± .019	.151 ± .013	.99

[a]Twenty-five obese and twenty-nine contemporary pigs were included.

[b]The model was $Y = b_0 + b_1X_1 + b_2X_2$ where Y = weight of empty body component, X_1 was D_2O space (lb) and X_2 = liveweight (lb).

Improvement of Dressing Percentage and Yield of Carcass Lean by Feed Restriction After Market Weight Has Been Attained

Jerome C. Pekas[1]

Introduction

Previous studies have shown that severe feed restriction of young swine caused a reduction of the real size and allometric size of visceral organs and of offal in general and that the responses were reversed by refeeding. The objective of this study was to explore the hypothesis that nutrients contained in the tissues of the visceral organs are salvaged during the process of atrophy induced by restricted feed intake and utilized for continued carcass and lean accretion and vital bodily functions. The pigs were allowed to attain market weight before feed restriction was initiated to allow maximum digestion and absorption and, presumably, tissue storage of dietary nutrients before the digestive organs and functions were caused to be dissolved. The concept was, first, to attain the desired target weight as quickly and efficiently as possible with the full complement of the digestive organs; and second, to improve carcass composition by inducing dissolution of the digestive and other visceral organs after their functions have been fulfilled and salvaging the nitrogenous nutrients for continued carcass lean accretion. The study involved two concurrent experiments: Exp. I compared the effects of prolonged terminal maintenance feeding, Exp. II compared the effects of continuous 80 percent feed restriction (throughout the growth and finishing phases) and of severe terminal restriction to effect rapid weight loss from pigs beyond the target weight.

Procedure

Forty-eight crossbred swine (Chester White, Landrace, Yorkshire, Large White; 51 lb initial weight) were assigned to eight treatment groups (6 pigs/group; 1 pig/pen) in two experiments and randomly assigned to locations within a building equipped with slatted floors and automatic temperature and ventilation controls. The target slaughter weight was 230 lb. The six treatment groups in Exp. I were fed *ad libitum* until the group average attained the target weight. Then feed was restricted to maintain body weight for 7, 14, 21, 28, and 42 days for treatments 2, 3, 4, 5, and 6, respectively, before the animals were slaughtered; treatment 1 animals were slaughtered without feed restriction. The three treatment groups of Exp. II (treatment I of Exp. I was the control comparison in this experiment) were fed and slaughtered as follows: treatment 1, *ad libitum* to target weight and slaughtered; treatment 7, 80 percent of *ad libitum* intake (treatment 1) throughout to target weight and slaughtered; treatment 8, fed *ad libitum* to 255 lb (110 pct of target weight), then feed was reduced daily to 80 percent of the intake of the previous day until body weight decreased to the target weight and the animals were slaughtered. Offal and carcass weights were recorded. Empty body slaughter weights were calculated by subtraction of the weight of ingesta, urine, and bile removed by emptying visceral organs. Empty body weight was employed in the statistical regression, variance, and covariance analyses. Carcasses were cut into wholesale cuts and then dissected in three fractions: the preferred lean fraction consisted of lean dissected from

the ham, loin, picnic, and Boston butt; the fat-skin-belly fraction consisted of the fat and skin from ham, loin, picnic, Boston butt and of the intact belly (lean from belly not dissected); the bone fraction consisted of only the bone in the carcass. Offal was subdivided into three fractions: viscera, abattoir trim (head, feet, prepuce), and all-other offal (ingesta, feces, urine, bile, blood, hair).

Results

The results of Exp. I are summarized in Table 1 and Figure 1. The period from initiation to slaughter was 93, 100, 107, 114, 121, and 135 days for treatments 1, 2, 3, 4, 5, and 6, respectively, as determined by the experimental design. The average initial, slaughter, and empty slaughter weights were 51.4, 231.5, and 226.4 lb, respectively, and treatment differences in these weights were not significant, as expected. Feed consumption, gain, and gain efficiency (Table 1) show that feed consumption increased significantly and in proportion to the number of days of maintenance feeding. The low level of consumption during the maintenance phase (no net gain) accounted for the significant and regressive decline of gain efficiency (gain/feed).

Carcass weight was significantly increased and offal weight significantly decreased by maintenance feeding. The shift of weight from offal to carcass significantly increased dressing percentage.

The weight of body, carcass, preferred-lean, and fat-skin-belly, as maintenance feeding was prolonged up to 42 days after the target weight was attained, are illustrated in Figure 1. Estimates of expected body, carcass, or carcass fraction weights, before target weight and if *ad libitum* feeding had been continued beyond target weight, are included in the graph for comparison. It is clear that carcass fractions of treatment 1 animals (animals not subjected to maintenance feeding) do not fall on the regression line for the five treatment groups which were subjected to various periods of maintenance feeding. The regression line for maintenance fed animals did not intersect the estimated *ad libitum* line near day 0. Nevertheless, a regression slope was established by day 7 and indicates that the effects of maintenance feeding were delayed about 7 days. The 7-day delay, or transition, likely involved induction of complex enzyme systems in carcass and offal tissues by the initiation of maintenance feeding. The following regression equations were obtained: fat-skin-belly fraction (lb/100 lb EBW) = 39.47 — .06181 (day MF), r^2 = .1202, P = .065; preferred-lean fraction (lb/100 lb EBW) = 30.19 + .06359 (day MF), r^2 = .1708, P = .0258; bone (lb/100 lb EBW) = 6.187 — .00457 (day MF), r^2 = .0146, P = .5324 where EBW is empty body weight, day MF is the days of maintenance feeding, r^2 is the coefficient of determination, and P is the probability that the regression coefficient (b) is zero. The slope of the regression line for the actual weight of these animals (226.4 lb empty body weight) was calculated from the regression equation for each of the two significant fractions and the regressions plotted. The slopes expressed as lb/day of maintenance feeding were: fat-skin-belly, -.140 lb/day (net loss); preferred-lean, +.144 lb/day (net gain). The yield of

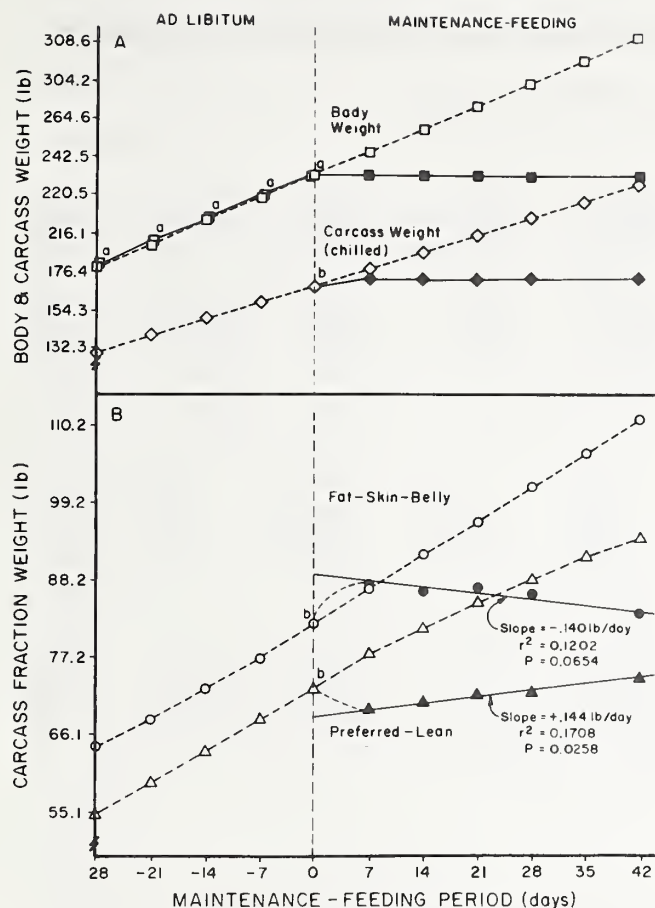[1]Pekas is a research physiologist, Nutrition Unit, MARC.

Figure 1.—Carcass responses to prolonged maintenance feeding (Exp. 1). Estimates of values expected if *ad libitum* feeding had been continued an additional 42 d or if animals had been slaughtered 28 d before initiation of maintenance feeding are included (estimates are joined by broken lines). Graph "A" summarizes body and carcass data. *Ad libitum* body weights were estimated assuming 1.9 lb daily gain as during the period before maintenance feeding. Carcass weight estimates were on the basis of 76.64 dressing percentage (from treatment 1; *ad libitum*) and 5 percent cooler shrinkage. Graph "B" summarizes the two soft tissue fractions. Estimates of net daily accretion of lean and fat were obtained by applying rates for swine of various body weights, reported by others, to body weights in graph "A." Estimated fat accretion was assigned to the fat-skin-belly fraction. Estimated lean accretion was divided; 90 percent to the preferred lean and 10 percent to the fat-skin-belly fraction (for lean content of undissected belly). It was assumed that skin weight did not change appreciably. The vertical line indicates initiation of maintenance feeding. The regression coefficients and lines were adjusted to the actual mean empty body weight (226.4 lb). The curved broken line indicates the delayed but profound transition of carcass fraction responses to maintenance feeding. The ■ , ◆ , ● , and ▲ symbols represent body, carcass, fat-skin-belly, and preferred-lean weights, respectively. Open symbols denote *ad libitum* feeding; solid symbols denote maintenance feeding. [a]Denotes the mean body weight (actual; n = 36) of these animals before maintenance feeding was initiated. [b]Denotes the mean fraction weight (actual; n = 6) of *ad libitum* animals (treatment 1) slaughtered the day maintenance feeding was initiated.

preferred-lean increased, yield of fat-skin-belly decreased, and yield of bone remained constant as maintenance feeding was prolonged. The three offal fractions (Table 1) were examined for evidence of the mechanism by which offal weight was reduced during maintenance feeding of market weight swine. There were significant treatment differences in each fraction; empty viscera and all-other-offal decreased, but abattoir trim increased during maintenance feeding.

The results of Exp. II are summarized in Table 2. Treatment 1 (*ad libitum*) reached the target weight in 93 days, treatment 7 (continuous restriction) in 122 days, treatment 8 (severe terminal restriction) in 115 days. The average initial, slaughter, and empty slaughter weights were 51.8, 234.4, and 228.8 lb, respectively. The means of overall gain, feed consumption, and gain efficiency are summarized in Table 2. Feed consumption was significantly increased and gain efficiency significantly decreased for both restricted treatment groups. Although there were differences among the treatment groups for weights of offal, carcass, and carcass fractions, the differences were not significant.

In conclusion, the results of this study demonstrate decisively that terminal maintenance feeding (feeding market weight swine to maintain weight by restriction to suppress continued gain) does improve the carcass merit of swine. The improvement is from a shift of weight from offal to carcass and from carcass fat to carcass lean. The procedure could be useful to improve carcass merit while hedging for more favorable market circumstances. The procedure could be especially beneficial for those markets which pay a reasonable premium for superior dressing percentage and carcass lean content.

Table 1.—Covariate-adjusted means of performance, slaughter, carcass fraction yield and yield efficiency, backfat, and offal fraction data (Exp. I)

Variable	Unit	0	7	14	21	28	42	Prob.[a]
				Days of maintenance feeding				
Performance data:								
Total gain	lb	180.8	177.5	181.9	180.3	183.2	183.4	.7559
Total feed consumption	lb	597.0e	620.6de	645.3cd	663.8bcd	681.4bc	701.5b	.0036
Gain efficiency	lb/lb	.304b	.287bc	.282c	.272cd	.269cd	.261d	.0226
Slaughter data:								
Carcass weight (warm)	lb	177.3c	180.6b	180.3b	180.6b	181.2b	181.2b	.0710
Offal weight (empty)	lb	48.9b	45.9c	45.9c	45.9c	45.2c	45.0c	.0710
Dressing percent	pct	76.6c	78.2b	78.0b	78.2b	77.8b	78.5b	.0652
Carcass fraction data:[f]								
Bone	lb	13.4	14.8	13.7	13.2	13.4	13.9	.1557
Yield efficiency (apparent) data:								
Preferred lean	lb/lb	.123	.112	.110	.109	.107	.106	.3872
Fat-skin-belly	lb/lb	.137bc	.142b	.134c	.132cd	.126d	.119e	.0001
Bone	lb/lb	.023bc	.024b	.021c	.020d	.020d	.020d	.0246
Backfat data:								
Thickness	in	1.4	1.5	1.6	1.5	1.5	1.5	.8371
Offal fraction data:								
Total viscera (empty)	lb	19.2b	17.4c	18.7b	17.6c	17.2c	16.5c	.0031
Abattoir trim	lb	16.8e	16.2e	18.2cd	17.7d	18.8bc	19.5b	<.0001
All-other offal	lb	18.0b	17.0bc	14.2de	15.1cde	15.8cd	13.6e	.0152

[a]Probability of > F value for treatment groups by covariance analysis; independent variable was empty body weight.

[bcde]Means in the same row that do not share common superscripts are significantly different.

[f]See Figure 1 for carcass fractions; preferred lean and fat-skin-belly.

Table 2.—Covariate-adjusted means of performance, slaughter, carcass fraction yield and yield efficiency, backfat, and offal fraction data (Exp. II)

Variable	Unit	Ad libitum control	Continuous restriction[a]	Terminal restriction[b]	Prob.[c]
			Treatment		
Performance data:					
Total gain	lb	183.0	183.6	181.0	.8371
Total feed	lb	601.2e	637.6de	671.1d	.0474
Gain efficiency	lb/lb	.305d	.288de	.270e	.0454
Slaughter data:					
Carcass weight (warm)	lb	179.0	181.0	182.5	.4453
Offal weight (empty)	lb	49.8	47.8	46.3	.4453
Dressing percentage	pct	76.5	76.5	78.5	.1543
Carcass fraction yield data:					
Preferred lean	lb	74.1	71.4	72.1	.7807
Fat-skin-belly	lb	82.2	85.5	86.9	.5388
Bone	lb	13.4	13.9	14.3	.3826
Yield efficiency (apparent) data:					
Preferred lean	lb/lb	.125	.112	.107	.2981
Fat-skin-belly	lb/lb	.137	.134	.130	.1436
Bone	lb/lb	.022	.022	.022	.8664
Backfat data:					
Thickness	in	1.4	1.6	1.4	.3039
Offal fraction data:					
Total viscera (empty)	lb	19.5d	18.5de	17.7e	.0942
Abattoir trim	lb	16.8e	17.4e	18.9d	.0647
All-other offal	lb	18.6d	19.6d	13.3e	.0700

[a]Feed restricted to 80 percent of control ad libitum intake throughout.

[b]Feed restricted to 80 percent of previous day allowance and adjusted daily from d 106 to slaughter.

[c]Probability of > F value (treatment effect) by covariance analysis: independent variable = empty body weight.

[de]Means in the same row that do not share common superscripts are significantly different.

Additional Growth Potential Revealed by Greater Than Normal Feed Intake

Jerome C. Pekas[1,2]

Introduction

Rate and efficiency of growth are the principal indicators of economic returns in animal production. The composition of diets has been adjusted in fine detail to maximize growth of contemporary genotypes of meat animals and especially of swine. Free choice (*ad libitum*) feeding of scientifically formulated diets to swine is a common practice in the 1980's. Information about growth, if feed intake could be increased beyond *ad libitum* or normal appetite, is missing. The energy requirement to maintain body weight is commonly considered to be proportional to the body weight (BW) or, more precisely, to the 3/4 power of body weight (BW$^{.75}$) of the animal. According to this concept, each increment of dietary energy intake above the maintenance requirement would be available for growth. If feed intake could somehow be increased beyond *ad libitum* intake and if the rates of digestion, absorption, and tissue utilization of the nutrients were not limiting, then the rate of growth should be accelerated. Since the proportion of energy for growth would be increased, the efficiency of growth should improve. Although the physiology of appetite regulation of feed intake has been explored for many years, there has not been a breakthrough. This study was conducted using an experimental method to introduce greater than normal quantities of diet. The method allowed exploration of the effects of greater than normal dietary intake, even before a method was developed to elicit voluntary ingestion of excessive quantities.

The objectives of the study were to observe the rate and efficiency of growth of swine receiving substantially more feed daily than *ad libitum* intake and determine if *ad libitum* feed intake is sufficient to attain the full genetically inherited potential for growth.

Procedure

Four pairs of littermate crossbred pigs (eight pigs total; Chester White, Landrace, Yorkshire, Large White) were used. One of each pair was the control (C) and was fed a conventional corn-soybean diet *ad libitum* (C; 100 pct). The other pig of each pair was surgically prepared with a gastric fistula. After recovery and regaining a normal appetite, the pig was gradually increased from 100 percent to 120 percent of control *ad libitum* intake over a period of 7 days. Feed intake was maintained at 120 percent of control *ad libitum* intake (on a grams-dry matter per lb-body weight basis) from day 8 to day 30 (23 days). This process is referred to hereafter as superalimentation (SA; 120 pct). The animals were fasted for 24 h and slaughtered. Carcasses were processed in a conventional manner. The ham, loin, picnic, and Boston butt were dissected into lean, fat, and bone fractions. The "other parts" (belly, jowl, hocks, neck, rib pieces) were not dissected.

Results

Body weight, 23-day gain, and 23-day gain efficiency are summarized in Table 1. Total feed intake increased by an average of 31 percent; this was the result of the 20 percent more dietary dry matter per unit of body weight and the 10 percent heavier body weights by day 30. Moreover, weight gain increased 40 percent from 31 percent more feed. This is a clear demonstration that substantial additional nutrients were recovered from the excess feed. Thus, dietary digestion, nutrient absorption, and tissue synthesis were not rate limiting. The increment of additional diet clearly was utilized for growth of body mass. Although the efficiency of growth was improved, the difference was not significant. Both the offal and carcass fractions of the body increased during superalimentation; these fractions accounted for 22 and 78 percent of the body weight increase, respectively (Table 2). Dissected lean mass (not including lean in the belly or jowl) accounted for 21 percent of the body weight increase; dissected fat mass (also not including fat in the belly or jowl) accounted for 32 percent of the body weight increase.

In conclusion, this exciting evidence shows that contemporary genotypes of swine have an inherited potential for growth which is substantially greater than growth attainable at *ad libitum* intake (average of 2.8 lb/day *vs* 2.0 lb/day). Feed intake clearly is an important limitation. Neither the capacities for digestion and absorption of excessive ingested nutrients nor the capacity of tissues to utilize the excess nutrients can be proposed as serious limitations. Although fat accretion accounted for more than 5.8 lb of the 18 lb body weight response, we must not lose sight of the fact that the SA pigs, because of their more rapid gain, were 18 lb heavier than the C littermate pigs after only 23 days. There is an abundance of evidence to show that fat deposition accelerates and lean deposition declines normally as pigs approach slaughter weight; daily net accretion of lean declines sharply after about 140 lb body weight while daily net accretion of fat continues to accelerate.

Table 1.—Summary of body weight, gain, and gain efficiency responses to super-alimentation over a 23-day period (n = 4; mean)

Parameter	Control (C)	Super-alimentation (SA)	Response[a] (pct of C)	Prob.[b]
Body weight (lb):				
Day 1	106.5	99.6	- 6.4	NS
Day 8[c]	124.3	123.7	- 0.4	NS
Day 31	170.4	188.5	+10.5	.05
Alimentation-dry matter; 23 days (lb)	156.3	205.3	+31.3	.025
Gain; 23 days (lb)	46.3	64.6	+40.0	.005
Gain efficiency; 23 days (lb/lb)	.30	.32	+ 7.3	NS

[a]Response - $\frac{(SA-C)}{C}$ x 100; percent of control (C).

[b]Two-way (treatment vs litter) analysis of variance. Prob. = statistical probability.
[c]Day 8 was the first day of superalimentation of 120 percent of the control.

Table 2.—Summary of the composition of the excess growth

Parameter	Control (C)	Super-alimentation (SA)	Response (SA-C) lb	Response (SA-C) pct
Body weight (lb)	170.4	188.5	17.97	100.0
Offal (lb)[a]	66.6	70.5	3.99	22.2
Carcass (lb)[b]	103.8	117.7	14.02	78.0
Dissected parts:				
Lean (lb)	47.8	51.6	3.81	21.2
Fat (lb)	17.6	23.4	5.78	32.2
Bone (lb)	9.7	9.5	-.24	-1.4
Other parts (lb)	28.7	33.3	4.67	26.0

[a]Offal includes skin.
[b]Carcass data obtained by measurement of the right half and multiplication of value times 2.0. Composition data obtained by dissection of four parts (ham, loin, picnic, and Boston butt) into lean, fat, and bone; "other parts" (belly, jowl, hocks, neck, rib pieces, etc.) were not dissected.